University of Tennessee, Knoxville
TRACE: Tennessee Research and Creative Exchange

Masters Theses
Graduate School

8-1989

Heat Transfer Model and Computer Program for a Direct-Fired Rotary Kiln

Steven J. Kirslis
University of Tennessee - Knoxville

Follow this and additional works at: https://trace.tennessee.edu/utk_gradthes

Part of the Chemical Engineering Commons

Recommended Citation

Kirslis, Steven J., "Heat Transfer Model and Computer Program for a Direct-Fired Rotary Kiln. " Master's Thesis, University of Tennessee, 1989.
https://trace.tennessee.edu/utk_gradthes/1344

This Thesis is brought to you for free and open access by the Graduate School at TRACE: Tennessee Research and Creative Exchange. It has been accepted for inclusion in Masters Theses by an authorized administrator of TRACE: Tennessee Research and Creative Exchange. For more information, please contact trace@utk.edu.

To the Graduate Council:

I am submitting herewith a thesis written by Steven J. Kirslis entitled "Heat Transfer Model and Computer Program for a Direct-Fired Rotary Kiln." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Chemical Engineering.

Jack S. Watson, Major Professor

We have read this thesis and recommend its acceptance:

George C. Frazier, John W. Holmes

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Steven J. Kirslis entitled 'Heat Transfer Model and Computer Program for a Direct-Fired Rotary Kiln.' I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Chemical Engineering.

Jack S. Watson

Jack S. Watson, Major Professor

We have read this thesis
and recommend its acceptance:

George C. Frazier

John M. Holmes

Accepted for the Council:

CW Minkel

Vice Provost
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirments for a Master's degree at The University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholary purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Steven J. Kirski

Date May, 1989

Heat Transfer Model and Computer Program

for a

Direct-Fired Rotary Kiln

A Thesis

Presented for the

Master of Science

Degree

The University of Tennesee, Knoxville

Steven J. Kirslis

August 1989

ACKNOWLEDGMENTS

It is essential to recognize the outstanding assistance from my major professor, Dr. Jack S. Watson, and my father for their patience and tireless review of this thesis. Their ardent support and encouragement merits my lasting gratitude. I also wish to thank Jeff Fleming and Dave Pitts of IT Corporation for their contributions in the model development.

ABSTRACT

An improved heat transfer model has been developed for a direct-fired rotary kiln. The model can be used to verify kiln design, to optimize operating conditions, to predict the temperature history of the solids, and to evaluate if local areas of the kiln will be overheated. The treatment of radiant heat transfer was based on the Reflection Method developed by Succec and applied by Gorog, and was extended to account for radiation from a flame. Some elements of the Resistive Network Method and Zone Method were incorporated in the model. This method results in a more straightforward and flexible treatment of radiant heat transfer than other methods of analysis. The model also accounts for conductive and convective heat transfer within the kiln and heat conducted through the kiln wall and lost from the outer kiln shell to the ambient surroundings.

The model divides the kiln into a flame region where the flame is present, plus a downstream gas region. The flame and gas regions are each subdivided longitudinally into kiln sections of equal length. A new method was devised to model the grey body emissivity of an axially centered flame of given area. It was treated as equivalent to a black body of reduced area. This treatment greatly simplified the calculation of radiant heat transfer to and from the flame. A method was devised for calculating the gas transmissivity for its own radiation in the Reflection Method. The model also includes an approximate treatment of the recirculation and entrainment of combustion gas in the flame region, and assumes plug flow

downstream of the flame region. A regression method was developed for calculating the emissivity of combustion gases of varying CO_2 and H_2O concentrations based on Hottel's real gas data. The temperature and heat transferred to or from the flame, gas, wall, and solid bed in each axial section of the kiln is calculated using the Reflection Method by simultaneously solving a set of algebraic expressions involving the emissivity, area, and radiative (geometrical) view factors for the various surfaces in the kiln. The model was verified with a computer program written in LOTUS 1-2-3 using a set of operating data from a direct-fired kiln used for the incineration of lightly contaminated soil. The model yielded good agreement between the calculated and reported values of the solid and gas exit temperatures as shown in Fig. 8.1-1 and Table 8.1-1. The percent error for the estimated solids exit temperature was 6.8 and for the gas was -3.2.

The new heat transfer model was also extended to provide an approximate treatment of heat transfer in IDF kilns. The model used two separate heat balances to (1) estimate the heat transferred from burning fuel in the outer gas to the outer surface of the inner shell, and (2) the heat transferred through the inner shell and radiated to the solid bed and inner gas. As with the direct-fired kiln, the kiln was divided into uniform longitudinal sections, each with constant temperatures and surface properties. The use of a constant outer gas temperature is only approximate because of the steep temperature gradient that exists between the bottom temperature where the fuel combustion occurs and the top temperature where the combustion gases exit. Model calculations for a hypothetical data set (no actual data were available) indicated approximate agreement with vendor reported kiln characteristics and temperature profiles.

This model is the first treatment of heat transfer in an IDF kiln reported in the literature.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

1.0 INTRODUCTION

Furnaces are widely used pieces of industrial equipment, and the mathematical modeling of heat transfer to predict the temperature and heat flux distribution in furnaces is of interest to industry for the improvement of furnace design and the selection of operating conditions for better efficiency. Models for heat transfer in direct-fired and indirect-fired rotary kilns, the type commonly used to incinerate hazardous waste, are developed in this thesis. The results calculated using the direct-fired kiln model are compared with experimental data from a small scale actual kiln used to incinerate hazardous waste.

The primary objectives of the thesis are (1) to apply the Reflection Method radiant heat transfer analysis to characterize the various heat flows and mechanisms of heat transfer within a direct-fired kiln and an indirect-fired kiln, and (2) to provide a more complete and realistic model for the direct-fired kilns than published treatments by including in the model a number of additional important effects. These include the effect of a radiating flame within the kiln, the effect of gas recirculation and entrainment, the effect of heat transfer to and through the wall by convection and conduction, heating of the solid bed by convection and conduction, and the effect of using a real gas data base to characterize the radiative heat transfer in the gas phase. The effect of gas circulation and entrainment, and the use of a real gas data base have not been considered in previously published treatments of heat transfer in a direct-fired kiln.

The prediction of the temperature profile within a kiln is needed to ensure proper heat treatment of solids in the kiln and to ensure that local areas of the kiln are not over-heated. Direct-fired kilns are essentially heat exchangers in which solids are heated by hot gases flowing in the freeboard above the bed. Material is fed co-current or counter-current to the gas flow as the kiln rotates. The material moves down the kiln due to a slight angle of inclination of the kiln axis. Indirect-fired kilns have two concentric cylinders between which hot combustion gases are passed to transfer heat to the inner steel cylinder which contains the solid bed. (See Fig. 1.0-1).

At the high temperatures of normal operation in furnaces, radiation is the dominant mode of heat transfer, and a considerable amount of effort has been applied to developing methods of calculating radiant heat transfer. The heat transfer is complex because it involves radiative exchange between the flame, gas, solid bed, and kiln walls as well as convection (solid and gas) and conduction between the solid bed and the wall. The complexity of the heat transfer phenomena encountered in rotary kilns has necessitated the use of a number of simplifying assumptions such as gray gas behavior, simplified geometries, and the neglect of end effects and axial heat transmission.[1-15]

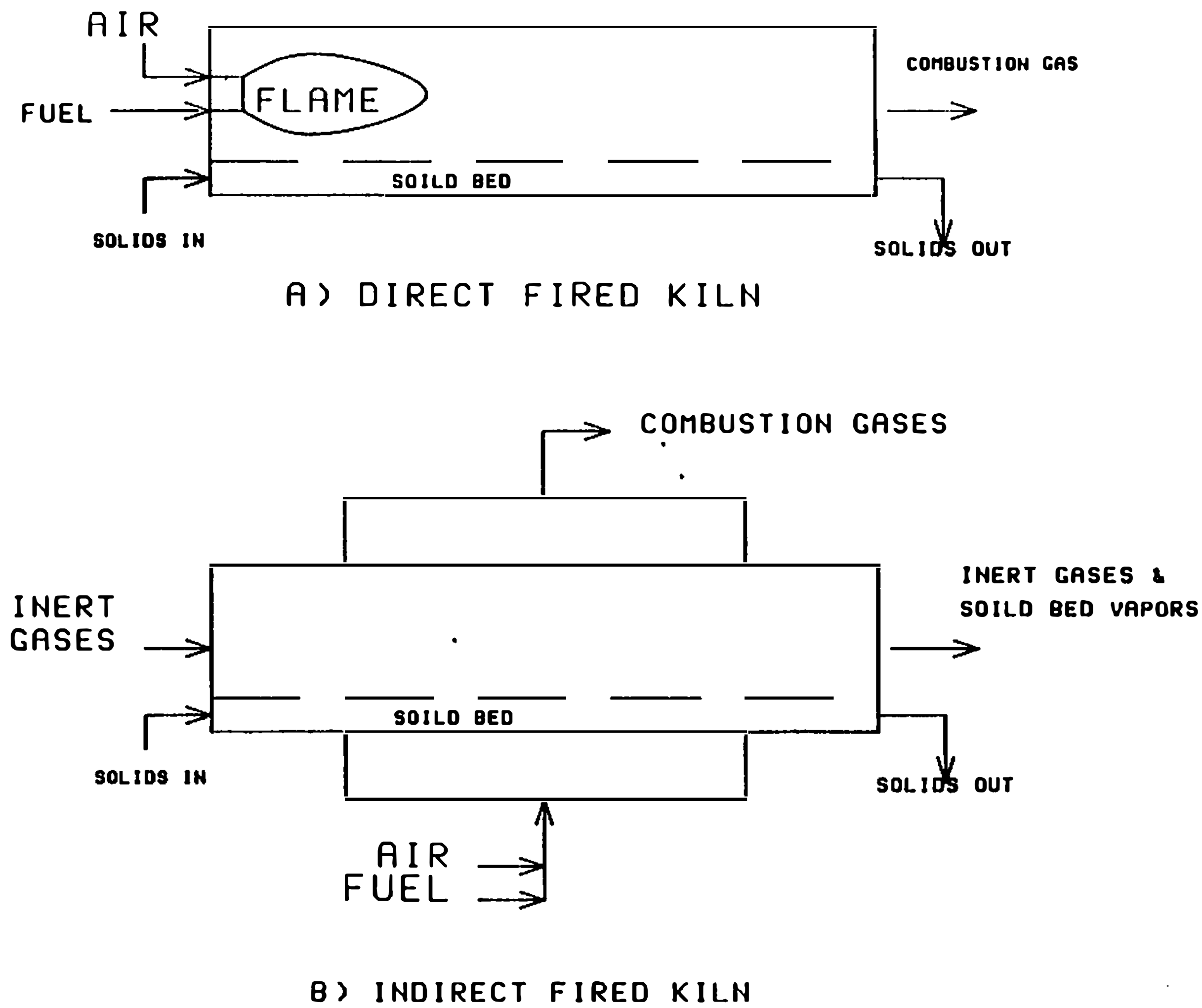


Figure 1.0-1. Direct and Indirect Fired Kilns

2.0 SELECTION OF THE BASIC RADIANT HEAT TRANSFER MODEL

A number of models for analyzing radiant heat transfer in enclosures such as a rotary kiln are described in the literature. The methods of analysis commonly used include the Zone Method[4], the Flux Method[5], the Resistive Network Method[2,3], and the Reflection Method[1]. Each of these approaches are valid for particular types of kilns and are based on the same basic heat transfer equations. However, each method has its drawbacks. The models which use the Zone Method[4] and the Flux Method[5] have not included a solid bed in the models. The Resistive Network Method is limited to treating the gas as a 'gray gas'[2,3]. It is difficult to account for axial heat transmission or kiln end effects in the Reflection Method and the Resistive Network Method. Each of the four methods of analysis will be described in the following portions of this section to indicate the reasons why the Reflection Method was chosen in this thesis as the basic model for radiant heat transfer.

No models for indirect-fired (IDF) kilns have been found in the literature. Modeling IDF kilns is a future area of work to be developed.

2.1 Zone Method of Analysis

The zone method of analysis, developed by Hottel and Cohen[17], is the most complete and theoretically sound mathematical model of radiant heat transfer. The zone method approximates the non-isothermal enclosure and gas by subdividing the enclosure and gas into surface and volume zones so that each zone is small enough that its temperature and radiative characteristics can be considered to be uniform. A gas volume and its adjacent wall surface may be at different temperatures. An energy balance at steady state is written for each surface and gas zone by equating the 'heat in' to the 'heat out' for each zone. The 'heat in' includes all energy generated in or absorbed by the zone from all the other zones in the kiln. The 'heat out' includes heat transferred to all of the other zones in the kiln. Each radiative interchange is obtained by determining radiative exchange factors for each zone pair combination in the enclosure, taking account of attenuation by intervening gas, and including the effects of reflection within the enclosure. The exchange factors for each zone pair determine the fraction of radiation leaving one surface that is transmitted to the other surface of the pair. For each surface the energy emitted is proportional to the fourth power of the surface temperature.

Total energy balance equations for each zone can then be drawn up, taking account of all forms of energy transfer in the enclosure such as convection of heat due to gas flow, chemical heat release, and net radiative transfer (interchange) with other zones. This leads to a set of simultaneous nonlinear algebraic equations in terms of the temperature of each zone, which on solution yield the temperature profile within the furnace, and this then enables the heat fluxes to be evaluated.

The evaluation of the exchange factors forms an essential part of the zone method of analysis. They are constructed according to the laws of radiation, taking account of the emissivity, absorptivity, and geometry of the radiating media.

To minimize the computational difficulty, the number of zone subdivisions is kept as low as possible. Unavoidably, this results in an approximate representation of a non-isothermal region by the finite number of isothermal subregions. With the availability of still larger computers, the subdivision could be made as fine as necessary to yield the desired accuracy, but the improvements would become progressively less. For some simple geometries, exchange areas have been calculated previously and are available in published tables[48]. Where tabulated data are not available, the exchange areas must be evaluated by numerical integration for each value of adsorption coefficient considered in the gray/clear gas model. To date none of the published zone method models have included a solid bed, presumably because it would involve added computational difficulties. Predictions by the zone method of analysis have been limited to the gas and wall temperature profile for a rotary kiln.

2.2 Flux Method

The basis of most flux methods of analysis is a balance for the flux of radiant energy in a specified direction through an elementary volume, derived on the assumption that the material within the element is optically gray (improved accuracy can be obtained by relaxing this restriction). The method considers a small elemental volume, or surface element in the furnace enclosure, and, by calculation of the net heat flux to and from that element in one or more directions, generates a total energy balance for that element. This procedure can be repeated for as many elements as required to obtain the desired degree of accuracy.

Differential equations are used to describe the unknown flux densities which are similar in form to those which describe mass, momentum, and energy transfer at a point, and these equations can therefore be combined and solved numerically.

The flux method has been limited in practice to consideration of only two flux directions (radial and axial) and a gray gas. Also, when the Flux Method has been applied to a rotary kiln, a solid bed has not been included in any published application of the method to date. The gases can be modeled as real gases using a gray/clear gas model, but this increases the number of flux components, and greatly increases the calculational difficulty, requiring faster computers. With the advances of computer capabilities, interest in this method may increase.

2.3 Resistive Network Method

The use of network representations to solve enclosure radiation problems was first suggested by Oppenheim.[19] To include radiation in a thermal network involving mainly convection and conduction, it is convenient to define a unit thermal radiative conductance, or radiant-heat-transfer coefficient, h_r, as follows:

$$h_r = q_r/A_1(T_1 - T_2) \qquad \text{Eqn. 2-3.1}$$

$$= \sigma F_{12}\ (\varepsilon_1 T_1^4 - \varepsilon_2 T_2^4)/(T_1 - T_2)$$

where:

σ = Boltzmann radiation constant

ε_1 = emissivity of surface 1

ε_2 = emissivity of surface 2

F_{12} = view factor between surface 1 and surface 2

A_1 = radiating surface area upon which F_{12} is based, sq. ft.

T_1-T_2 = temperature difference between surface 1 and surface 2, R

h_r = radiant heat transfer coefficient, in Btu/hr sq ft R

q_r = radiant heat flow, Btu/hr

Once a radiant-heat-transfer coefficient has been calculated, it can be used similarly to the conductive and convective heat transfer coefficients because the rate of heat flow is treated as if it is proportional to the first power of the temperature difference, and radiation can be incorporated directly in a thermal network where the temperature difference is the driving potential, as in convection and conduction. From Eqn. 2.3-1, it is clear that the value of h_r varies with the values of T_1 and T_2, as well as their difference.

If radiation heat transfer is the dominant mode of heat transfer[33], as is common in s rotary kiln, the convective heat transfer coefficient can be approximated in the following form:

$$h'_{cv} = q_{cv}/A(T_1^4 - T_2^4) ,$$

where the convective heat transferred now is treated as if it depends on the difference of the fourth power of the absolute temperatures. This form is related to the non-radiative coefficient defined by

$$h_{cv} = q_{cv}/A(T_1 - T_2)$$

by the expression,

$$h'_{cv} = h_{cv} / ((T_1^2 + T_2^2)(T_1 + T_2))$$

A conductive heat transfer coefficient for the radiation-dominant case can be defined similarly. The resistive network defined in this manner can incorporate conductance and convection directly in the radiative resistive network.

The resistive elements in the radiative network are functions of the view factor (or angle factor), surface emissivities, and the emissivity and transmissivity of the intervening medium. The resistive network method, unlike the other methods discussed, is only applicable for a gray gas[30] i.e. the emissivity, transmissivity, and absorptivity of the medium are constant fractions of those for black body radiation. Because a real gas containing CO_2 and H_2O emits and absorbs radiation only at discrete wavelengths,the transmissivity of a real gas for its own radiation frequency (wave length) is much lower than the transmissivity of a resl gas for thermal radiation (black body spectrum) from solid surfaces. Therefore when radiation emitted by a real gas is reflected from a surface, the gas reabsorbs more of the reflected radiation, so that only a smaller amount remains after the next reflection from a solid surface. This, of course, assumes that the reflected light has principally the spectrum of the incident light. (The total light leaving the surface will contain both reflected light and emitted light.) However for a gray gas, the transmissivity is much higher (equal to 1 minus the emissivity of the gas) and allows more reflected energy to be transmitted to the solids. For this reason, use of the gray gas assumption in predicting the radiative exchange in rotary kilns may lead to significant errors, even greater than 20 percent[1] if the surface reflectivity exceeds 0.2.

The great advantage of a resistive network model is that it can be easily set up for any number of surfaces in the presence of an isothermal gray absorbing-emitting medium and solved by straightforward matrix algebra. The method solves a system of algebraic equations simultaneously, usually by a matrix inversion technique using a digital computer. The simultaneous system of equations is generally solved for the radiosities of the respective surfaces. Once all the radiosities are obtained, the net radiative heat transfers and temperatures from the n surfaces and the gas are determined. Details of the derivation, and an explanation of how the network diagram is constructed and the algebraic method used to solve the network is discussed in the literature[31,32,33]. Brimacombe et al.[1,2,3,4] have used the resistive network method extensively to model a rotary kiln with a solid bed with fair success, even though axial radiation and end effects from the kiln end surface were neglected. They stated that the predicted maximum flame temperatures, flame lengths and maximum heat fluxes were in broad agreement with the limited industrial data available.

2.4 Reflection Method

In the Reflection Method (Succec[15]), the radiation leaving each emitting surface or gas volume element is traced through one or more (diffusive) reflections from the surrounding surfaces which intercept the radiation before final absorption. Account is taken of the energy absorbed from the emitted rays and the reflected rays by the freeboard gas and by the solid surfaces encountered. The net radiant loss for each surface (or gas) is the difference between the total amount of radiant energy emitted from a surface (or gas) and the total amount absorbed by the surface (or gas) from the energy emitted by the gas and other surfaces in the enclosure.

The emitted energy from the kiln wall or solid bed is traced through two reflections and the energy remaining after the second reflection is considered to be distributed between the solids and wall as if they were black bodies. 'Reflection' as used here refers to diffuse reflection (cosine law), rather than specular reflections (angle dependent). The amount of radiant energy attenuated by the gas for each ray is equal to the difference between the energy initially emitted (or reflected) and that which is transmitted through the gas to either the solid bed or kiln wall.

A real gas adsorbs radiation only within certain discrete wavelengths. Therefore, the gas is clear to other wavelengths, but the radiant energy lying within the wavelength regions where adsorption occurs is rapidly attenuated. For this reason the gas absorbs almost no radiation emitted from the solid surfaces after the second reflection, since all the radiant energy within the adsorption bands has been absorbed previously, i.e. the gas becomes transparent after only two reflections. Also, after two reflections a large percentage of the radiant energy initially emitted by the solid surfaces has been absorbed by the kiln wall, or solid bed, or gas. (The spectral distribution of reflected radiation from a gray or black body is the same as the initial ray from a gray or black body). For these reasons the approximation is permissible that the energy remaining after two reflections is distributed between the kiln wall and solid bed as if they were black bodies. That is, all of the energy of the third reflection from the solid bed is assumed to be absorbed by the wall, whereas the energy of the third reflection from the wall is assumed to be absorbed by the wall and solid bed according to the view factors from the wall to itself and to the bed.

The path of energy emitted by the freeboard gas is traced through only one additional reflection after the gas-emitted radiation originally hits and is reflected from a solid surface because of the high absorptivity of a real gas for its own radiation. The energy remaining after the second reflection is considered to be completely absorbed by the freeboard gas. An important item in the Gorog and Brimacombe model was the development of a method to calculate the transmissivity of a gas for its own radiation. This method is discussed in detail in Section 4.5.

A radiation balance using the Reflection Method has been developed by Gorog[1] for a rotary kiln modeled as a single well-mixed tank. This simplified treatment does not provide a method for representing temperature profiles nor the variation of other parameters from one end of the kiln to the other. (See Fig. 2.4-1). Based on these assumptions this modified Reflection Method was used to describe the net radiant loss for the freeboard gas, kiln wall and solids. In Gorog's[1] work there was no verification or demonstration of the applicability of the radiative balance by comparison with experimental observation.

2.5 <u>General Description of the Modifications of the Reflection Method Used in the Present Model</u>

The fundamental radiation balance used to model radiative heat transfer in the present work is based on the Reflection Method proposed by Succec[24]. The present work develops a more complete heat transfer model than that developed by Gorog[1]. The model includes (1) a flame added to the the radiative balance,

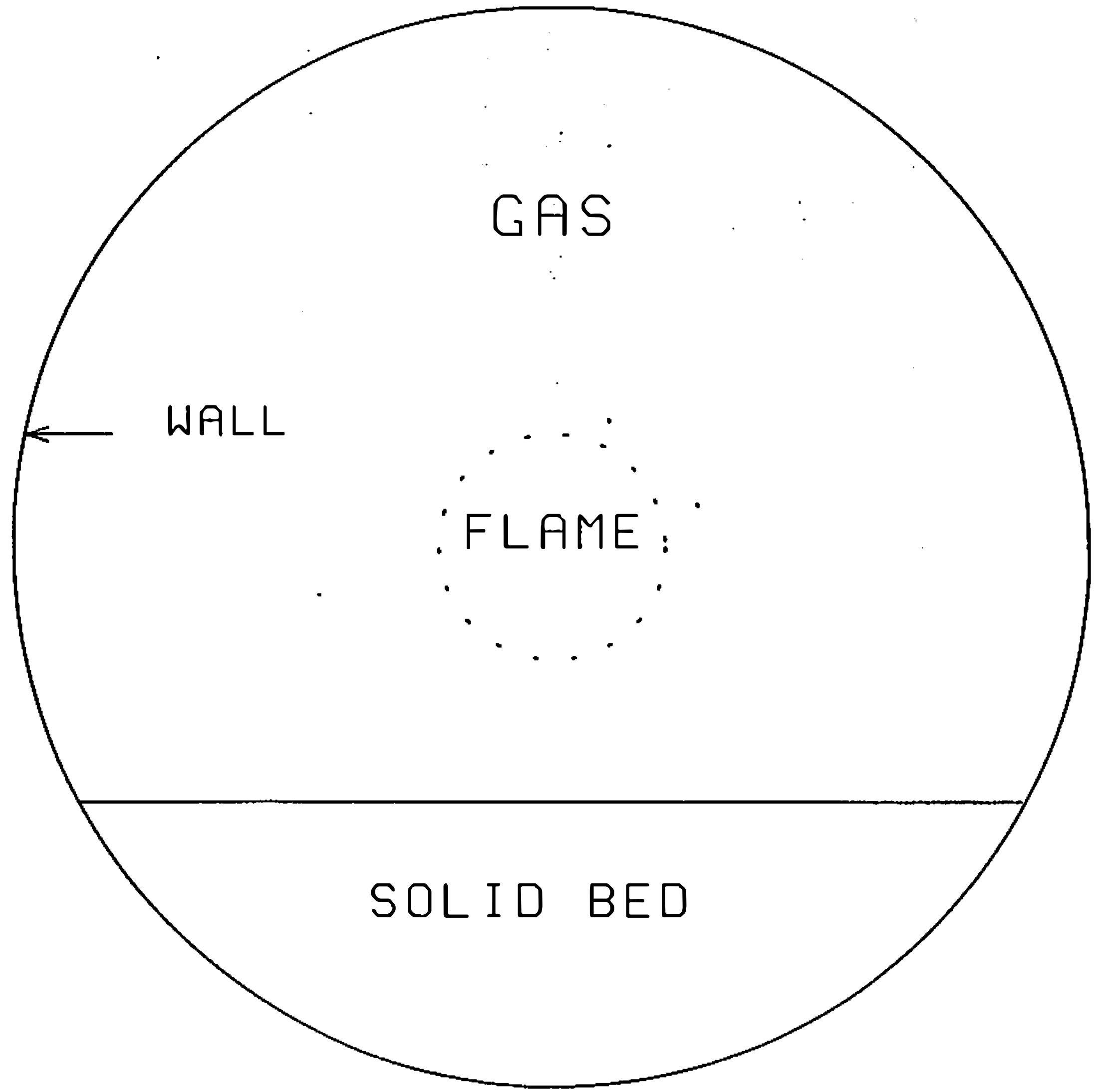


Figure 2.4-1. Kiln Cross Section

(2) a gas flow model which divides the kiln into a flame and gas region, each of which is 'zoned' in sections, (3) recirculation of gases in the flame region, (4) a flame heat release model for a turbulent flame, (5) a method to estimate the emissivity and absorptivity of the kiln gas based on real gas data, (6) a method to estimate the emissivity of the flame, and (7) calculation of the heat transferred by conduction and convection within the kiln and through the kiln wall.

The present work is the first model published in the open literature to (1) include a flame in the radiative balance, (2) use the Reflective Method and divide the kiln into sections, (3) include recirculation of gases in the flame region, and (4) calculate the gas emissivity and absorptivity based on a real gas database. The validity of the model developed is demonstrated using a computer program and verified with a set of experimental data obtained from operation of a direct-fired rotary kiln which included a flame and solid bed.[33]

The model developed is for a radiation balance for an enclosure with two gray surfaces (i.e., wall and solid bed) and one black body or axially centered gray body surface (e.g., the flame) with any selected CO_2 and H_2O concentration for the gas in the enclosure. In the present work, the model has been applied to a rotary kiln with the flame as an interior modified black body surface and the solid bed and wall as gray surfaces. The temperature profiles of the three surfaces and the gas determine the flow of heat within the enclosure. All parameters required to calculate the radiation balance are variable inputs to the program, and can be modified as needed for different geometries, surface properties, and kiln gas compositions. CO_2 and H_2O are the only gas constituents which are considered to absorb or emit radiation. The flame itself is treated in Section 4.7 as a gray body to account approximately for the presence of 'soot', or ash particles in the flame. (The gray body flame is treated as a black body of reduced area. Consideration of 'soot' and ash or solid particles in the gas surrounding the flame has been excluded from the model.) Convective heat transfer from the gas to the two gray surfaces (wall and bed) and conductive heat transfer between the gray surfaces (wall to bed) are considered in the model. Heat loss through the enclosure shell is also estimated for a shell of 3 separate materials. Conduction through these shell layers is considered, as well as convection and radiation from the outer surface of the shell to the ambient surroundings.

Numerous simplifications and assumptions are required in developing a heat transfer model for direct-fired kilns. The combined effect of these simplifying assumptions on the model accuracy is difficult to ascertain. Gorog[1,2] has quantified the individual error in percent of total radiative exchange (flux) in a rotary kiln resulting from three such assumptions: (1) the neglect of axial radiation resulted in less than a 15% error[1], (2) the assumption of a constant circumferential wall temperature resulted in less than 3% error for the net radiant energy transfer to the solid burden[2], and (3) the effect of the gray gas approximation led to an error of less than a 20% for wall and solid emissivities greater than 0.8[1]. The first two assumptions were incorporated in the present work while the gray gas approximation error was avoided in the present model by using a real gas data base to estimate gas emissivities and gas absorptivities.

The errors have not been estimated in the literature for other assumptions such as (1) neglecting recirculation of combustion gases, (2) neglecting kiln end effects, (3) the extent of solid bed mixing (i.e., temperature varying with bed depth), (4) coarseness of kiln zoning, and (5) the effect of postulating that the temperature of each element in each zone (gas, flame, wall, and bed) remain constant in each zone. In actuality the temperatures may vary by 100°K or more from one end of a zone to the other. The cross relations and co-variances of these effects with each other make them difficult to estimate separately. For instance, axial radiation impacts several of these assumptions: kiln end effects, kiln zoning, and recirculation of combustion gases. In a number of cases, some of these effects will partly compensate for each other. Further studies will be required to quantify the effects of all of the assumptions used in this or any similar model.

Experimental data to quantitatively evaluate the heat transfer uncertainty resulting from these assumptions are not available at this time. For the ERRU (Environmental Rapid Response Unit) kiln, the author's crude estimates, based on limited sensitivity calculations, of the effects of these assumptions on model predictions of total heat transfer to the solid bed are as follows: (1) recirculation of combustion gases, 5 to 10%, (2) kiln end surface effects, less than 5%, (3) extent of solid bed mixing, 10 to 20%, (4) coarseness of section zoning, 5 to 10%, and (5) determination of average temperature within a section, 5 to 20 %. The background and basis for each of these estimates is discussed in the particular section concerned with each of these phenomena.

The influence of recirculation of combustion gases, coarseness of zoning, and definition of the average temperature within a zone for the gas and solid bed are discussed in Section 3.2 and 8.0. An increase in the number of zones would be expected to reduce these effects. The results of the heat transfer analysis with and without recirculation are discussed in detail in Section 8.0.

Axial radiation and end effects also affect the temperature distribution in the flame, the gas surrounding the flame, and the downstream gas. These effects are discussed in Section 4.3. These effects cool the flame and heat the gas and are similar to the effects of recirculation. A study that used the zone

method[4] and included axial radiation and end effects indicated fair agreement with gas and flame temperatures in the flame region compared with experimental data. This study did not include recirculation effects because the author[4] considered there was little gas recirculation.

The temperature gradient of the gas and solid bed in the flame region is very steep, with a temperature change of several hundred degrees in each zone. The model selects 'average' effective radiative temperatures of the gas and solids in each zone that are characteristic of heat transfer in that zone. If the heat transfer were based on the exit temperatures of the bed and gas of the previous section, more heat would be transferred to them from the wall and flame than if the calculations were based on the average temperatures of the bed and gas in a section, particularly for the initial sections where the temperature gradient is steep. The steady-state radiative temperatures of the gas and solids in each zone were determined from a trial and error solution. Gas and solids temperatures were estimated such that the heat transferred to the gas (or solids) plus the enthalpy of the entering gas (or solids) corresponded to the temperature estimated. In this calculation, all of the processes affecting heat flow within the zone are considered: combustion, mass flow, radiation, convection, and conduction. No discussion was found in the literature of the basis by which the average temperature within each section is selected.

3.0 MODEL DEVELOPMENT OF THE KILN FLOW PATTERN AND FLAME MODEL

The determination of temperature distribution in a rotary kiln involves the simultaneous solution of three basic problems:

a) The flow pattern of gases and solids.

b) Heat release rate by fuel combustion.

c) Heat transfer to and from the flame, gas, solid bed, and wall.

Rotary kilns of widely varying characteristics are used in industrial operations, and approximate models have been developed to estimate the operating characteristics of particular kiln designs. However, published data on the operating characteristics of rotary kilns which are detailed enough to verify the models are scarce. The particular type of kiln selected to verify the model (a kiln[25] with two skewed high intensity oil burners) was chosen because (1) sufficient data were available to verify the model, and (2) this type of kiln is used in several important applications such as incineration of hazardous waste (for example, soils contaminated with dioxin). The kiln modeled had an internal diameter of 4 feet and was 16 feet long. The burner configuration for this kiln produced a short, bushy, turbulent flame, which was observed to have a flame length of about three feet. The general features of the model developed could be applied to kilns of other dimensions, but appropriate modifications would be required to describe other flame types and burner configurations. The model needs information on the particular flame length, flame heat release rate, flame diameter, solid bed characteristics, and other operating characteristics of the specific kiln studied.

The three major problem areas mentioned above are discussed separately in the following sections for the kiln selected to demonstrate the model. The simpler sub-models developed for treating each of these basic problems are combined in the final complete model.

3.1 Mathematical Model of the Gas Flow Patterns in a Kiln

Previous Work -

Heat flow and temperature distribution in a rotary kiln will be affected by the gas flow patterns in the flame, in the gas region surrounding the flame, and in the gas region downstream of the flame. The complex mass flow equations describing these turbulent flows are difficult to solve analytically in ways which can be incorporated in a heat transfer model. Therefore, most modeling efforts resort to simplifying assumptions for the flow patterns, such as breaking up the kiln volume into a number of well-stirred tanks or assuming that the gases would move in plug flow in some reactor regions. The term 'well-stirred tank' is used to indicate a section of the kiln in which the temperatures of the gas and solid surfaces are constant but not necessarily equal. In the Zone Method (Hottel)[16] and the Resistive Network Method (Brimacombe)[2,3], the volume and surfaces are subdivided into a large number of zones with uniform temperature and concentration within each zone. (See Figs. 3.1-1 and 3.1-2).

A flow model used by Field et al.[26] considers the burner region of the kiln as a partially stirred reactor, and the remainder of the kiln is assumed to be operating with plug flow (Fig. 3.1-3). Figures 3.1-1, 3.1-2, and 3.1-3 illustrate the nature of the flow patterns in these models. Other mathematicsl treatments of flow patterns are discussed in the literature (Hottel[17], Spalding[49]).

<u>Current Work</u> -

The Reflection Method of radiant heat transfer as spplied by Gorog[1] makes use of a single well-stirred reactor gas flow model, and average values of the kiln operating variables to predict radiant heat transfer within the kiln. This approach has been modified in the present work to consider the gas flow in the kiln as taking place in a combination of well-stirred reactors with differing temperatures, gas compositions, and gas flows in each. The kiln volume is divided transversely into a flame region, containing the flame surrounded by gas, and a gas region containing no flame (See Fig. 3.1-4).

3.1.1 <u>Selection of Flame Length in the Modeled Kiln</u>

The selected burner configuration and kiln dimensions used in the calculation were taken to be those of the EBRU[25] kiln.

A model or calculational procedure to predict the flame length for this type of burner configuration is not available in the

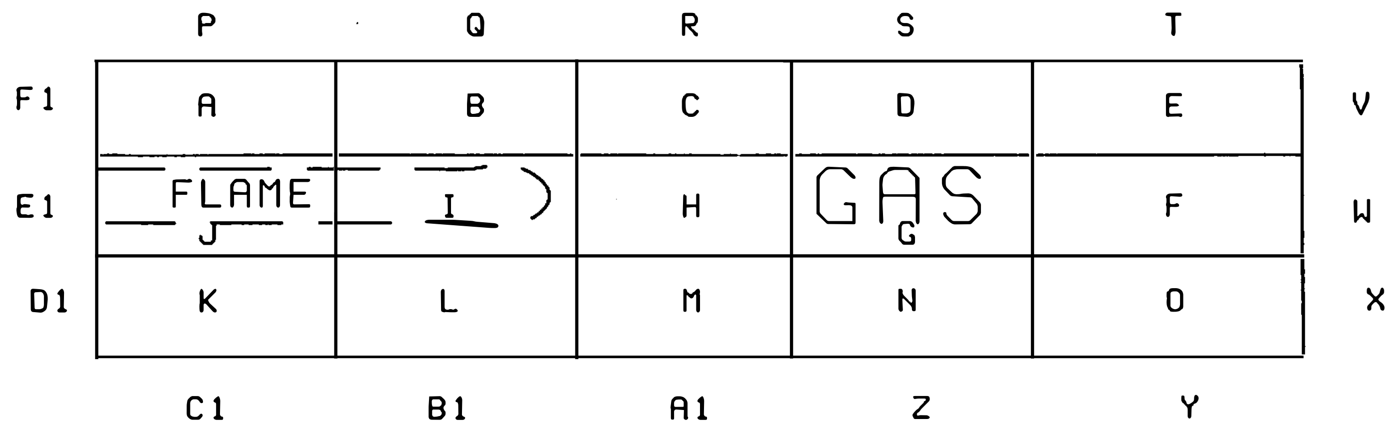


Figure 3.1-1. Division Zoning for Zone Method

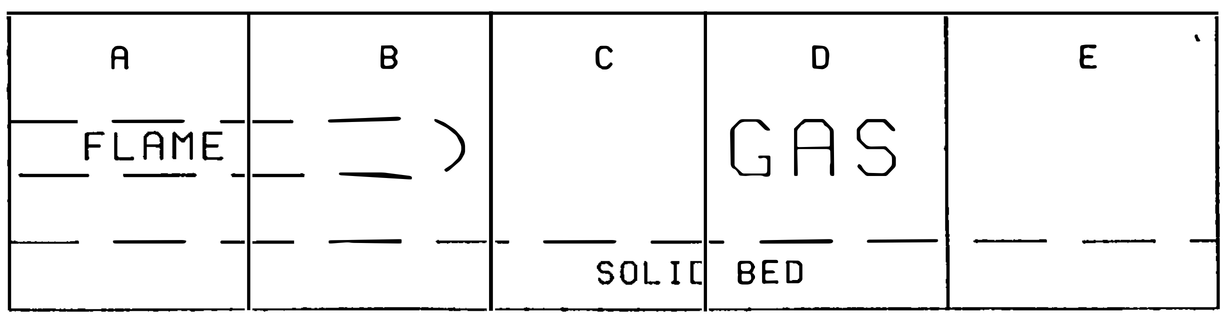


Figure 3.1-2. Division Zoning for Resistive Method

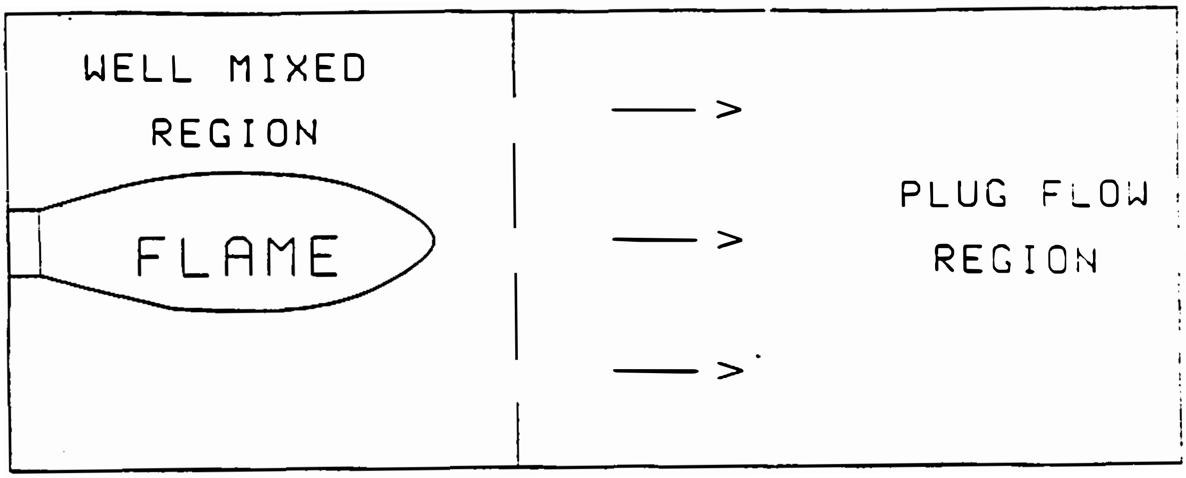


Figure 3.1-3. **Partially Stirred Reactor with Plug Flow**

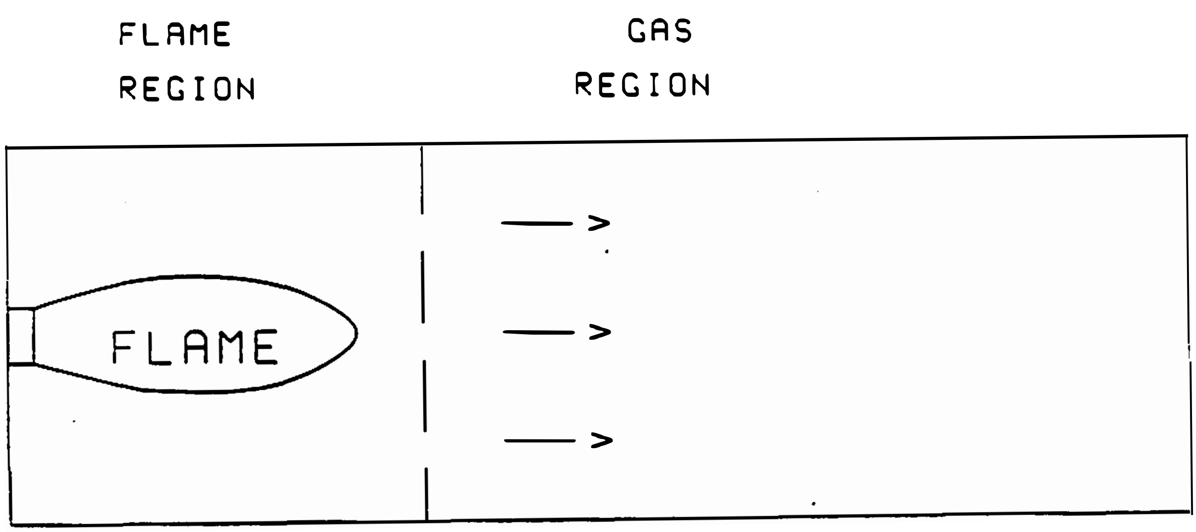


Figure 3.1-4. **Flame/Gas region of Direct Fired Kiln**

literature. Only procedures for the diffusion type flames observed in large kilns are available[8]. The flame in the present model is not a diffusion type flame because of the turbulent mixing induced by the skewed burners and the excess stoichiometric air introduced through the burners. The diffusion flame length models in the literature (for example the work of Thring and Newby[37]) are not applicable for this particular type of burner configuration and kiln operating mode, but they could be used in this model when the appropriate type of burner is used. Their models are based on single axial jet behavior where the length of the flame is controlled by the rate at which air is entrained into the jet stream, resulting in a long slightly divergent flame. It was not possible, therefore, to justify the flame length on the basis of correlations for diffusion flames. The flame length used in the calculation, three feet, was that experimentally observed during the collection of the data set for the EERU kiln (listed in Appendix D).

3.1.2 Selection of Zone Length in Modeled Kiln

The number of well-stirred tank sections used determines the coarseness of the resulting representation of the temperature profile. A larger number of sections is particularly important in regions of steep temperature gradient such as the flame region. However, increasing the number of well-stirred regions beyond two for the flame region significantly increases the calculational difficulties required to determine the temperature profile in the kiln. These difficulties are compounded for the flame region when the effect of recirculated gases is considered. (See below Section 3.2 - Recirculation and Entrainment of Combustion Gases). The flame region is modeled in this study as s combination of four 'well-stirred reactors'. The flame itself is modeled as an axially symmetrical cylindrical flame which is divided into two well-stirred tanks in series (Fig. 3.1.2-1). The gas in the flame region surrounding the flame is divided into two annular well-strirred tanks. This diagram is explained further in Section 3.2. For the kiln region downstream of the flame, the temperature gradients are less steep and heat transfer results are less sensitive to zone length.

The lengths of stirred tank sections mentioned in the literature (Brimacombe[3]) are between one and three feet. Brimacombe reported that shortening the section lengths further does not affect the resulting temperature profile significantly. For the present model two 1.5-foot long flame sections were considered sufficient to model the flame, for the reasons given in the following. A single 3-foot long flame section model would not provide a way to describe any temperature gradient in the flame region. Further, the use of two sections to model the flame (1) provides a more realistic temperature of the flame and surrounding gas in the flame region than using one section, snd (2) allows the calculation of the effect of recirculated gsses to be performed without unreasonable difficulty. Dividing the flame region into more

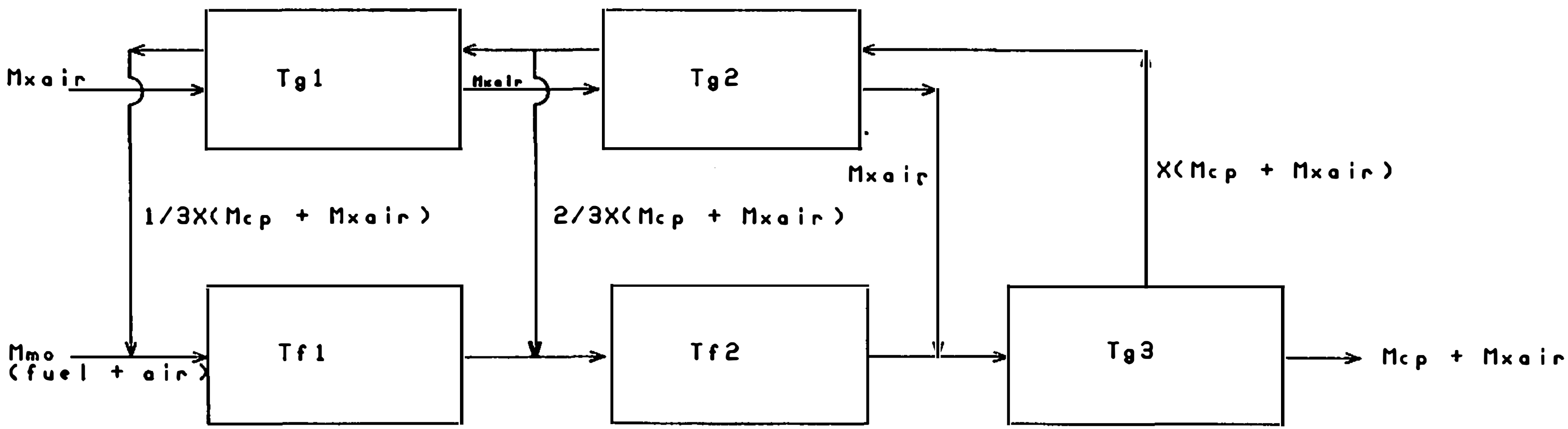


Figure 3.1.2-1. Block Diagram of the Flame Region

than two sections was felt to be unjustified for this short flame of the present kiln model in light of the reported small increase in accuracy, and the associated increased computational difficulties. The present model could be extended to incorporate a larger number of sections in the flame region for kiln designs with longer flames. The Discussion of Results (Section 8.0) compares the temperature distribution resulting when the flame consists of one three foot section with that when it contains two 1.5 foot long sections.

The gas surrounding the flame is also modeled as two well-stirred annular tanks in series. The remainder of the kiln downstream of the flame is considered as the gas region (without a flame present) and is modeled as a series of 'well-stirred tank' sections each 1.5-foot long. In the gas region, the gradient of the temperature profile within the kiln does not change abruptly, and 1.5 foot long sections are considered to be reasonable.

3.2 Recirculation and Entrainment of Combustion Gases

Previous Work -

Recirculation is the reverse flow of fluid from a point in the downstream section of a jet, with re-entrainment of this fluid into the jet nearer the injection source. If additional air is added outside the jet, this gas may also be entrained in the jet. Recirculation and entrainment are important effects to include in the model because they significantly increase the temperature of the gas surrounding the flame (by adding hot combustion gases from the down stream gas region) and decrease the flame temperature (by the entrainment of the lower temperature gases surrounding the flame) and hence affect heat transfer. The amount of gases entrained is a function of the burner configuration and operating characteristics. The amount of gases recirculated depends on how the air (that required for combustion and any excess air used) enters the kiln. If an adequate supply of secondary air is available to fill the vacuum created by the jet, less recirculation from the jet itself will occur, and recirculation will not be as significant to heat transfer in the kiln.

The effect of gas recirculation has not been treated in heat transfer models for rotary kilns found in the literature survey. Jenkins[28] discussed the amount and significance of this phenomenon for some kiln types. For a particular kiln, Jenkins predicted (using the Curtet correlation) a recirculation ratio of 1.87[28]. However, Jenkins did not incorporate the recirculation results into an overall heat transfer model. For a particular kiln (Johnson[34]), the amount of recirculation predicted by the Thring and Newby correlation[37] and the Curtet, et al., correlation[39] was found to be in fair agreement with the experimentally measured value of m_r/m_o (the ratio of mass recirculated to mass fired). The measured value was 1.05, while the Thring and Newby correlation predicted a value of 1.6, and the Curtet, et al. correlation predicted a value of 1.1. A more closely applicable entrainment model for the type burner configuration modeled in these calculations has not been found in the literature.

The basic entrainment correlation has been verified reasonably well in a number of experimental investigations (for example Beer[30] or Barchillon and Curtet[31]). More detailed discussion of the equations used to describe entrainment is included in Appendix A. More refined theories of confined jets have been proposed, such as the work of Curtet et al.[29], and Becker[32]. The literature indicates that a swirl burner increases mixing in the flame region (Neissen)[33] even further, and it is expected that the skewed burner configuration would also increase mixing.

<u>Current Model</u>-

The effect of recirculation and entrainment of gases by the flame is addressed in the present work with a simple model, drawing on the work of Thring and Newby. The recirculation/entrainment phenomenon is illustrated above in Fig. 3.1.2-1. This pattern shows that downstream gas is recirculated to the second gas section of the flame region and that part of the second section gas is recirculated to the first gas section. The correlation of Thring and Newby, as modified by Field et al.[26] was used to estimate the mass of gas recirculated to and entrained from the surrounding gas. See Fig. 3.2-1. The Thring and Newby correlation states that the jet entrains as a free jet and the entrainment, m_r, (in addition to the initial jet flow, m_o) up to any distance x from the burner nozzle to this point is given by the equation (Eq. 3.2-1):

$$m_r=[0.32(\rho_a/\rho_o)^{1/2}(x-6d_o)/d_o m_o]-m_o \qquad \text{Eq.3.2-1}$$

where ρ_a = density of gas entrained in the jet, lb/ft^3

ρ_o = density of jet stream, lb/ft^3

m_o = mass fired through the burner lb/hr

m_r = additional flow at distance x due to recirculation and entrainment

x = distance from the burner nozzle, ft

d_o = burner nozzle diameter, ft

This correlation, based on empirical studies of entrainment for a free jet, indicates that the degree of entrainment by the flame *per unit jet length* is proportional to the axial distance from a point $6d_o$ downstream of the burner. The $6d_o$ distance is required for the jet to become fully developed. At x/d_o less than 6, the entrainment rate *per unit jet length* is lower, increasing progressively with distance until it stabilizes at the constant value corresponding to Eq. 3.2-1. Consequently, to account for the lower entrainment rate in the jet region (first flame section) where the distance x from the burner is less than 6 nozzle diameters (24 inches for the EBRU flame)[25], the mass of gas entrained by the second section of the flame in the modeled kiln was arbitrarily taken to be twice the mass entrained in the first section of the flame (in place of equal entrainment rates per jet length). This is seen above in the block diagram (Fig. 3.1.2-1) where 1/3 of the recirculated gas is entrained in the first flame section while 2/3 of the recirculated gas is entrained in the second flame section. The resulting flow pattern is shown in the block diagram of Fig. 3.1.2-1. Increasing the recirculated fraction of combustion gases would

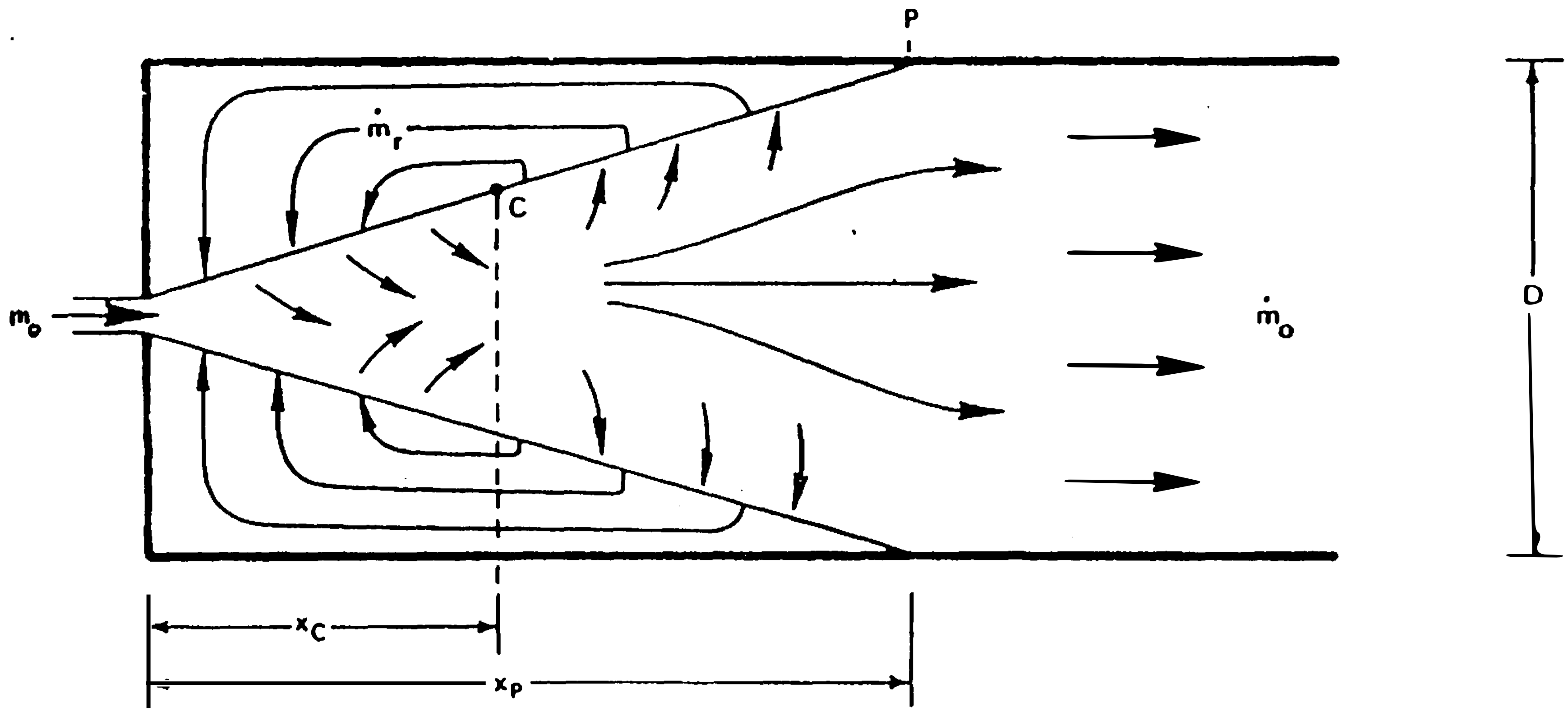


Figure 3.2-1. Gas Recirculation of a Free Axial Jet

effectively increase the mixing in the flame region.

The overall mass balance of the flame region requires that the total mass entering the region (the sum of the excess air and the mass fired through the burner) be equal to the mass leaving the flame region (the mass of the combustion gas products plus the mass of excess air). Expressed mathematically,

$$M_o + M_{xair} = M_{cp} + M_{xair} \qquad \text{(Eq.3-2.2)}$$

Note also that this equation requires that $M_o = M_{cp}$, where M_o includes the stoichiometric mass of air required to burn the fuel and M_{cp} includes the mass of nitrogen in the stoichiometric amount of air. If extra air is introduced with M_o, the extra mass is included in M_{cp}. Also, the mass of gas recirculated must be less than or equal to the total mass entrained in the flame, or less this mass for the case with added secondary air.

The effects of recirculation and entrainment can be qualitatively thought of as a partial mixing of the gas surrounding the flame with the flame. The surrounding gas is cooler than the flame. The principal results of considering recirculated gases in the flame region are the increased temperature in the gas surrounding the flame, the decreased temperature in the flame sections of the flame region, and the resultant lowering of the heat transfer in the flame region of the kiln. These effects are discussed further in Section 8.0

(Results and Discussion). Downstream of the flame region, the jet is considered to be completely dissipated and the gas is completely mixed. In this region it is assumed that the gas temperature within each section is uniform.

The application of this model to the present work is approximate in light of the differences between a free jet for which correlations are available and the short turbulent 'bushy' conical-shaped flame used in the kiln modeled. Data from the operation of the ERRU kiln provide no information regarding recirculation nor results which could be compared with the Thing Newby correlation. However it will be shown later (see Section 8.0) that the temperature profile, as indicated by the shell temperatures, is more closely predicted by a model including recirculation. Also, the exit temperature in the solid bed was lower than could be accounted for with a hot flame not cooled by recirculation. The flame region is modeled in the approximate way (shown in Fig. 3.1.2-1) as a combination of four 'well-stirred tank' sections. This model provides an approximation of the entrainment phenomenon. The mass of gas recirculated, $X(M_{cp} + M_{cp})$ is allowed to be a variable input in the program, and, as discussed above, 2/3 of this amount is recirculated in the second section and 1/3 in the first section of the flame region.

The correlation of Thring and Newby was modified slightly as discussed in Appendix A in calculating the amount of gas recirculated to make allowance for the broader conical angle of the observed short 'bushy'-shaped flame in the EBRU kiln as compared to the longer, narrow-angled shape of a diffusion type flame. The use of a wider flame angle results in the flame envelope striking the enclosure wall (where developed flow is assumed to begin) closer to the burner. This results in a shorter distance over which entrainment can occur. Consequently, less gas is entrained by the shorter flame modeled than would be entrained by a longer diffusion type flame. This modification of the Thring Newby theory is detailed in Appendix A. The modification results in 1/3 as much gas being recirculated as for a longer flame. Using the modified correlation, the mass of gas recirculated was calculated to be 3/4 of the mass of air and fuel fired through the burner. (See Appendix A for details).

3.2.1 Temperature and Composition of Recirculated/Entrained Gases

The gas downstream of the flame region is composed of combustion gases (including the nitrogen content of the combustion air) and excess air. Following the method of Thring Newby[37], and Thring[34], the downstream (third section) gas of this temperature and composition is recirculated to the second gas section of the flame region. See Fig. 3.1.2-1. The temperature of the gas recirculated to the first gas section is that of the second gas section. These recirculated gases in the first and second gas sections are entrained in the flame.

The initial gas temperature for each gas section was calculated by an enthalpy balance of the secondary excess air mass flow and recirculated gas mass flow entering and leaving each gas section. The details of this calculation are given in Appendix B. (See Eq. B11 in Appendix B). For each section, this initial temperature was then used in the radiation balance to determine the heat gained by the gas from the flame and wall as the gas reaches its final section temperature. This procedure will be discussed in further detail in the discussion of the program development.

The composition and heat capacity of the gas entrained by the flame were assumed to be those of the recirculated gas. The effect of mixing the secondary air and recirculated gas on the heat capacity of the gas entrained by the flame is considered to be small since the compositions were very similar (primarily nitrogen) and the heat capacities were approximately the same.

Thring and Newby made the assumption that the secondary air is entrained before any recirculated gases are entrained. Their assumption was based on a burner configuration where the secondary excess air was introduced immediately around the burner nozzle. In the present model secondary air was assumed not to be entrained directly into the flame. In the ERRU kiln for which calculations were made[26], the secondary air enters in other ways, mainly through leaks around the kiln end seals and feed chute. (The kiln was operated at a negative gauge pressure of about 0.3 to 0.5 inches water to prevent leakage out of the kiln of potentially hazardous gases). The amount of leak air (approximately 65% of the stoichiometric air) was determined by an overall heat and mass balance based on the data obtained from the ERRU kiln. If cool leak air were entrained directly into the flame, it would cool the flame, and reduce heat transferred to the solid bed.

Further details of the fluid flow model for the flame region are discussed in Appendix A. The enthalpy balance is discussed in more detail in Appendix B.

3.2.2 The Effect of Using a Single Zone for the Flame Section

Recirculation and entrainment in the flame was modeled both for a single (3 foot length) section and for two (1.5 foot length) sections. The recirculation of combustion gases modeled as a single section is a much simpler subset of the block flow diagram (Fig.3.1.2-1 above), and a description is given below in Fig. 3.2.2-1. Except for the number of sections in the flame region, the heat and mass balance calculations were carried out in the same way. The results of the comparison are given in Section 8.0 (Results and Discussion).

3.3 Chemical Reaction and Heat Release

Previous Work -

The combustion process is a chemical reaction. The rate of reaction depends on the concentrations of the the fuel and oxygen, and on flame temperature. The rate of reaction can be controlled either (1) by the rate at which reacting molecules are brought together, 'diffusion controlled combustion' or (2) by 'kinetically controlled combustion', where the reaction rate

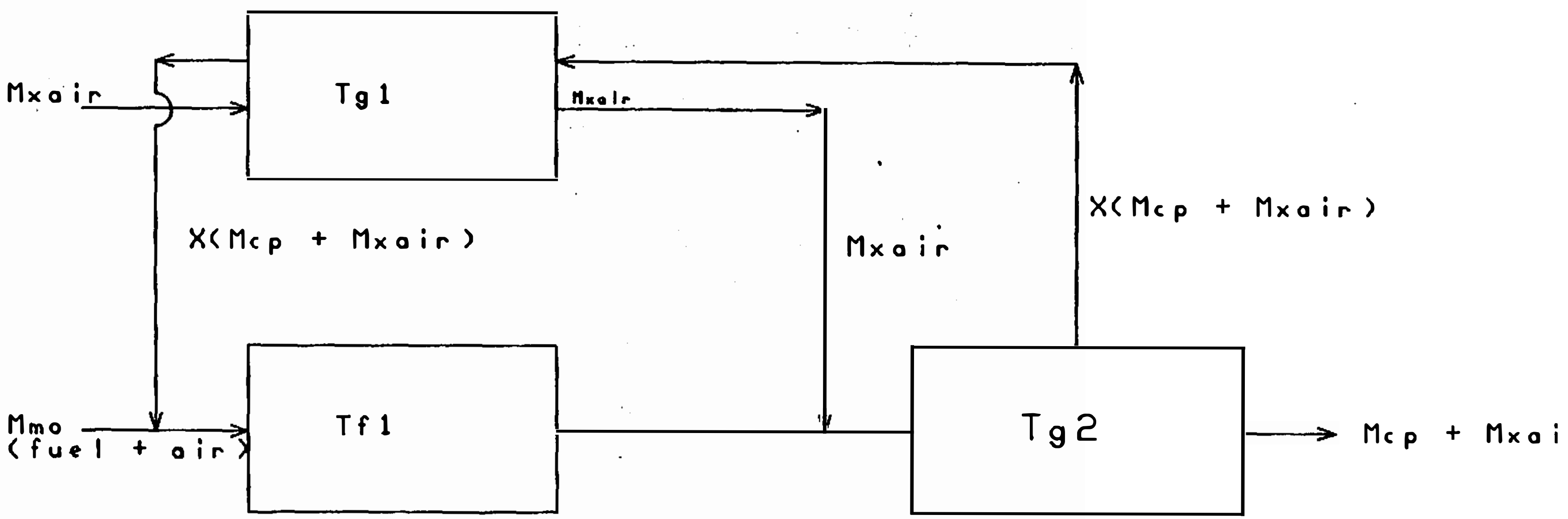


Figure 3.2.2-1. Block Diagram of Single Section Flame Region

is limited by chemical reaction rate constants. Under some circumstances both mechanisms can contribute significantly to the overall rate of reaction.

Diffusion controlled combustion is generally the limiting case for combustion of flames in those kilns where the reaction rate constants are high and the fuel and air react as soon as they are mixed together by turbulent diffusion. Generally, the fuel used in kilns (atomized fuel oil or pulverized coal suspended in 10% to 20% of the stoichiometric amount of air), enters the kiln at a high velocity. For diffusion control, the remaining air required for combustion enters as 'secondary air' at a lower velocity around the burner nozzle. The rate of combustion is then determined by the rate at which the secondary air is entrained into the high velocity fuel jet stream (or flame shell). In this process, the fuel stream is depleted of oxygen, and combustion occurs on the outer edge of the fuel stream. Flames of this type in large kilns can range in length from 10 feet to 60 feet depending on the burner configuration, operating conditions, and firing rate. (See for example Thring[34], Brimacombe[3], Johnson[35], Jenkins[28], or Sarofim[36]).

Kinetically controlled combustion occurs when the rates of mixing are extremely high (or when the fuel has been vaporized and premixed with the air prior to combustion) and the rate of reaction is not limited by the supply of oxygen or the removal of combustion gases, but principally by the rate constant of the chemical reaction. The kiln modeled falls into this category because the fuel stream is well- mixed (due to the burner configuration) with slightly more than the stoichiometric requirement of air (110%), and hence the rate of burning is not likely to be limited by the supply of oxygen in the fuel stream. Additional secondary air (about 65% of the stoichiometric amount) enters into the kiln (though not through the burner) and contributes to the surplus of air for combustion.

An argument has been made by Williams[37] that a combustion process of the type modeled is not entirely controlled by the kinetic reaction rate because the atomized fuel oil droplets must be evaporated before combustion occurs. Either diffusion of oxygen to the oil droplet or evaporation of the oil droplet could be the rate limiting step in the combustion process.

Similar rate limitations have been studied by Lee, Thring, and Beer[38] for the burnout rate of soot in the later stages of combustion, where the flame has entrained a sufficient amount of air so that combustion is not limited entirely by diffusion of oxygen only. At this later stage of combustion, the relative magnitudes of the reaction rate due to the diffusion rate of oxygen to the soot particle and the kinetic rate of the soot burnout are considered similar[38]. However, the short, intense flame observed in the kiln modeled is strong evidence that the combustion was not controlled by diffusion of oxygen into the flame envelope (as in diffusion flames).

Current Model -

Unfortunately, very little information is available in the open literature to model heat release rates in flames of the type used in the particular kiln for which the model was applied. Most kilns operate with long narrow flames which are under diffusion control, and hence the models used in the literature were developed for these type flames. However, some useful information can be extracted from the following observations on diffusion controlled flames:

1. Several experimental studies have been made or reported which indicate that 80% of the heat is released in the first half of the flame length. (See for example Cross and Young[39], Johnson[35], Jenkins[38], and Brimacombe[8]) This result suggests that the slower reaction in the second half of the flame is primarily the burnout of soot and/or CO formed in the flame, and only in part is the result of combustion of vaporized fuel.

2. There is some short distance (typically up to 6 burner diameters) for diffusion controlled flames before jet stabilization and entrainment of gas occurs (Thring and Newby)[37]. Combustion is slow or absent until sufficient air is entrained into the fuel jet. In the kiln modeled, the distance before combustion occurred was visually estimated to be a few inches (about one burner diameter), suggesting sufficient mixing of air for almost immediate combustion.

3. Model and experimentally measured temperatures in diffusion flames increased throughout the length of the flame. (See for example Johnson[35], Jenkins[38], Brimacombe[8]).

As discussed above in the flow model (Section 3.2), the division of the short flame region into two sections instead of one section provides a better description of fluid flow with recirculation for the kiln modeled in this study. To provide a positive increasing temperature gradient in the flame region, at least a two section flame region is required. From measured temperature profiles in diffusion flames[3], it may be inferred (as discussed below) that (1) with kinetically controlled flames more than half of the combustion reaction also takes place in the first flame region and that (2) the temperature increases throughout the length of the flame.

The first inference is consistent with simple bimolecular reaction rate theory where reaction rates generally vary directly with the product of the concentrations of the reactants. The concentration of fuel in the first section is higher than in the second section, while the oxygen concentration decreases from the first to the second section to a lesser degree due to entrainment. Consequently one would expect more fuel to be burned in the first section. In the second section, the fuel and air have been preheated nearly to the maximum combustion temperature in the first section, and the burning of the remaining fuel served to heat the combustion products to the maximum flame temperature in the second section. It has been observed in the ERRU kiln that the maximum shell temperature is in the vicinity of the second section of the flame (see Fig. 8-1.1 and Appendix D). It is clear that the gas temperature must decrease beyond the flame region since no internal heat is generated but heat continues to be lost from the gas region beyond the flame. But, as discussed below, if too large a fraction of the combustion heat were generated in the second flame section, the relative temperature rise in the second section predicted by the model would be too large.

The three observations quoted above in this section and the subsequent discussion led to a choice of 70% combusted in the first section. This choice is slightly less than that of diffusion flames discussed in the above observations (observation 1). Sensitivity calculations using the computer model (developed in this thesis) were made which indicated that a value of at least 60% and not more than 80% is required for the model to predict reasonable temperatures, i.e., where the second section is slightly hotter than the first section (observation 3 above).

4.0 DEVELOPMENT OF RADIANT HEAT TRANSFER MODEL

The primary intent of the thesis is to develope and demonstrate the validity of a heat transfer model for a rotary kiln including a number of modifications and improvements over previous models. The initial model is based on the Reflection Method[34] as developed by Gorog and Brimacombe[1]. The modifications include the additions of a flame region, and division of both the flame region and the downstream gas region into a number of well-stirred zones to account for axial variation in temperature. The modified model considers convective and conductive modes of heat transfer, as well as radiative heat transfer. Further modifications involve an improved method for treating the emissivity of a flame and the use of a real gas data base to estimate the emissivity and absorptivity of the gas as a function of the solid and gas temperatures.

The overall model is then a set of algebraical equations representing for each kiln zone all of the ways (radiation, convection, and conduction) in which heat is transferred between zone components (gas, solid bed, wall, and flame). In the flame region zone, the heat added by fuel combustion and the effect of gas recirculation on heat transfer are also represented in the algebraical equations. This set of complex equations for the temperature of each component in each zone is solved simultaneously by trial and error. For a particular set of operating conditions (fuel, air, and solid bed feed rate), the solution involves selecting a trial set of component temperatures for a particular zone, calculating the heat transfer and temperature changes of each component in the zone which determine the entering temperatures in the successive zone. The original set of trial temperatures for a zone are modified until they are consistent with the heat balance and other constraints represented by the set of simultaneous equations.

For example, the wall temperature is selected such that the heat transferred to (absorbed by) the wall is equal to the heat conducted through the wall refractory and lost to the ambient surroundings from the shell. If a different wall temperature were selected, there would not be a balance between the heat transferred from the flame and other kiln components to the wall and the heat transferred through the wall. (See Section 5.1 and 6.1 for further discussion). The gas temperature is selected such that the heat absorbed (or lost) by the gas (composition and mass) is sufficient to raise (or lower) the enthalpy of the gas corresponding to the temperature selected. Similarly, the solid bed temperature is determined in the same fashion as the gas temperature. The flame temperature is specified such that the sum of the flame combustion products and heat transferred from the flame to the gas, wall, and solid bed is equal to the heat released in that zone of the flame. In this way, the temperature of each component in each zone can be simultaneously determined with independent component constraints. For a particular zone for a selected set of trial component temperatures, different sections of the LOTUS 1-2-3 worksheet simultaneously calculate the heat transferred, the gas emissivity, shell heat loss, and the enthalpy of the gas, flame combustion products, and solid bed.

The radiation, convection, and conduction balances determine the net heat gained or lost from the gas and each surface for a given set of temperatures. The set of gas and surface temperatures selected (by the user) must satisfy the overall balance (Eq. 4.0-1) and any further constraints, such as steady state operation, (including heat transferred by convection and conduction).

The overall balance for the total kiln or any particular zone in the kiln is represented by the following overall heat and mass balance equation:

$$H_{air} + Q_{comb} = \Delta H_{gas} + \Delta H_{solids} + Q_{shell\ loss} \qquad \text{(Eq. 4.0-1)}$$

where,

H_{air} = enthalpy of the entering combustion gas and excess air

Q_{comb} = heat of combustion of the fuel

ΔH_{gas} = change in enthalpy of the combustion gas and excess air

ΔH_{solids} = enthalpy of the solids

$Q_{shell\ loss}$ = heat conducted through the wall and lost from the outer shell

At the steady state kiln conditions, the temperature of all kiln components from the beginning to the end of each zone remain constant with time. The temperature of each component will make a discontinuous change (step) to the temperature in the next zone which will be determined by the constraints described by the set of simultaneous equations for that zone. Further discussion of steady state constraints for the solid bed, gas, wall and flame are included in Sections 6.1-1, 6.1-2 and 6.1-3.

4.1 Reflection Method of Analysis

The heat transfer model developed uses the Reflection Method (Succec)[34] to predict the heat transferred by radiation within each section of the kiln. The Reflection Method radiation balance, as presented by Gorog[1], treated the entire kiln as one large section with two surfaces (wall and solid bed) and a participating gas, without a flame present.

Radiation is emitted by the solids and gas in accordance with the Stefan-Boltzmann law of radiation which requires that the rate, $\dot{Q}_i$, at which the total radiation is emitted from a surface i at temperature T_i, is proportional to its surface area, A_i, surface emissivity, ε_i, and surface temperature T_i to the fourth power. This relationship is expressed mathematically as follows:

$$\dot{Q}_i \text{ emitted} = \sigma A_i \varepsilon_i T_i^{\,4} \qquad \text{(Eq. 4.1-1)}$$

where the σ is the Stefan-Boltzmann constant.

In the Reflection Method, the radiation initially emitted by a surface is followed through several (diffuse) reflections from the enclosure surfaces, taking account of the amount of radiation absorbed and reflected by the solid surfaces at each interception, and of the amount of radiation absorbed by the gas in the enclosure between surface interactions until all the initially emitted radiation has been absorbed. As the method was applied by Gorog[1], the radiation initially emitted by a solid surface was followed through two reflections, after which so little radiation remained that it was considered completely absorbed on its next interaction with a solid surface. The number of reflections which need to be followed, of course, depends upon the absorptivity of the surfaces.

The radiation emitted by the gas, on its initial collision with a solid surface, was partially absorbed and partially reflected. A large part of the reflected radiation was absorbed during passage through the gas, since the absorptivity of the gas for its own (reflected) radiation is high. On the next (second) collision of what remains of this reflected radiation with a solid surface, again it was partially absorbed and partially reflected. So little of the initial gas radiation remained after this reflection that it was considered to be completely absorbed by the gas during its next (second) passage through the gas.

The fraction of radiation which is absorbed by a surface i is determined by its absorptivity, α_i, which for a gray body is equal to its emissivity, ε_i. The reflectivity, ρ_i, defines the fraction reflected by an opaque solid, which is equal to $1-\alpha_i$.

Air containing combustion products emits and absorbs radiation only in particular wavelength bands. Otherwise it is transparent to radiation. Its absorptivity, α_g (a function of gas composition, radiation wavelength distribution, and temperature), is the fraction of incident radiation absorbed in traversing the gas. The transmissivity, τ_g, the fraction transmitted, is equal to $1-\alpha_g$. The radiation characteristics of the gas are discussed in detail in section 4.5.

When the kiln geometry, governing view factors, and the radiation characteristics of the solid surfaces and of the gas (emissivity, reflectivity, and transmissivity) are specified, equations can be written for each emission and absorption step in the radiation balance. The radiation paths, including reflections with a flame, and the associated equations are discussed in Section 4.2.

This process will be demonstrated in the following sections for a simplified example where the enclosure contained one gas, no flame, and two surfaces (solid bed and wall). The individual emission, absorption, and reflection terms will be developed for the radiation from each of these emission sources. Reflection diagrams for the solid bed surface and gas are shown in Fig. 4.1.4-1 and Fig. 4.1.6-1.

4.1.1 <u>Construction of a Radiation Balance Using the Reflection Method</u>

To construct a radiation balance in a kiln section using the Reflection Method, the first step is to calculate the radiation emitted from each surface in the section. As discussed in Section 4.3, several simplifying assumptions were made in this model including the neglect of axial radiation to adjacent zones and kiln end surface effects. The surface emits radiation to the surrounding surfaces as governed by the view factors, which in turn are determined by the geometry used to model the enclosure. The view factor from one surface area to another is the fraction of radiation leaving the first surface which is intercepted by the second surface. The sum of the view factors for one surface in an enclosure to all the surfaces in the enclosure (including itself) is unity i.e.

$$\sum_{j=1}^{N} F_{ij} = 1$$

The view factors used for each section of the kiln are based on the areas of the wall, solid, and flame in each section, as well as the kiln configuration. The view factors in each region are taken to be the same for each section. Determination of these factors are discussed in Appendix C.

As radiation passes through the gas in the enclosure, the gas absorbs a fraction of the radiation. The remainder is transmitted to the receiving surface as determined by the view factor. All the radiation leaving a surface is either absorbed by the gas or intercepted by the surfaces in the enclosure. The intercepted radiation will be partly absorbed and partly reflected (diffusely). By tracing the emissions of radiation from a surface and its subsequent (diffuse) reflections and absorptions, the fraction of the emitted energy absorbed by the gas and by all the surfaces in the kiln section can be estimated. Sections 4.1.4 through 4.1.6 discuss the equations required to trace radiation emitted, reflected, and absorbed by the gas and surfaces.

The amount of radiation emitted and absorbed by the surfaces and by the gas in a section of the kiln is a function of their temperatures and their emissivities, absorptivities, and reflectivities. To construct the radiation balance, the emissivity, absorptivity, and transmissivity of the gas must be known as a function of temperature. Likewise the absorptivity, emissivity, and reflectivity of the solid surfaces must be known. Finally, the geometry for each section of the kiln must be known to determine the view factors.

At steady state the temperatures within a section of the kiln must reach constant values such that the net energy gained or lost by the section is zero. This is the basic overall energy balance for a section. (See Section 4.2 for the detailed drawings of the radiation paths used in the radiation balance and the resulting set of equations from which kiln heat flows and kiln temperatures are calculated).

4.1.2 The Absorption of Radiation Originating from a Solid Surface

Previous Work -

In the Reflection Method[11,1], the radiant energy emitted from a solid surface is traced through two reflections, and the energy remaining after the second reflection is distributed to the solid surfaces in proportion to their view factors, as if they were black bodies. The amount of energy attenuated by the gas for each ray is the difference between the energy initially emitted or reflected and that which is transmitted through the gas to a solid surface.

$$I_{absorbed} = I_{initial} - I_{transmitted}$$

For a real gas, absorption only occurs within discrete wavelengths. Therefore the fraction of energy from a solid surface attenuated by successive reflections is decreased for each reflection since there is less radiant energy lying within the wavelength region where absorption occurs. For this reason the gas absorbs almost no radiation after the second reflection since all the radiant energy within the absorption band has been absorbed previously, i.e. the gas becomes essentially transparent after only two reflections. Also after two reflections, a large percentage of the radiant energy initially emitted has been absorbed by the gas or solid surfaces. For these reasons, the energy remaining after two reflections is distributed between the solid surfaces as if they were black bodies. This is of course, an approximation, but the remaining energy is so small that small errors in its distribution can be neglected.

Current Work -

There is no difference between the Reflection Method model discussed above for radiation from solids and that used in the present model. It may be noted that if some of the radiation were specularly reflected from a curved surface, there would be a different distribution of radiation due to the focusing effect of the curved surface. This would require a different set of view factors for reflected radiation for the balance to be exact. However, in the present work only diffusive radiation is considered.

4.1.3 The Absorption of Radiation Originating from the Gas

Previous Work -

For radiation emitted by the gas, the path of emitted energy is traced through only two reflection because of the high absorptivity of a real gas for its own 'banded' radiation (as discussed in Section 2.4). After the second reflection, the energy initially emitted has been largely absorbed by the gas and solid surfaces, and the remaining energy is assumed to be completely absorbed by the gas during its next passage.

Current Work-

The same method for the absorption of radiation originating from the gas was used in the present work. Description of the gas emissivity, absorptivity, and transmissivity of the gas for its own radiation are discussed in Sections 4.4 and 4.5.

4.1.4 Derivation of Equations for Distribution of Radiation Originating from the Solid Bed

In this section, the equations are derived for describing the distribution of radiation originating from the solid bed for an enclosure containing two solid surfaces (wall and solid bed) and gas. The radiation is traced through two complete reflections. The number of radiation paths leaving (and view factors for) a surface is determined by the number of surfaces the surface can 'see'. The view factors for reflected radiation assume that the radiation has been diffusely reflected.

The radiation from the solid bed can only 'see' (be intercepted by) the wall, and its view factor, F_{sw}, the fraction of radiation emitted by the bed which is 'seen' by the wall, is equal to 1. The radiation reflected from any area of the wall can see other areas of the wall as well as the solid bed, so that two view factors are required to describe the reflected radiation from the wall. The fraction of radiation from the wall intercepted by itself is defined as F_{ww}, and the fraction of radiation from the wall intercepted by the solid bed is defined as F_{ws}. In the equations listed in Section 4.2 and the actual computer program (see Appendix E), the terms involving F_{ww} are included. However in the following description, the F_{ww} terms are omitted in order to simplify the description. These F_{ww} terms are similar in form to the terms involving F_{ws} and are shown in Fig. 4.1.4-1.

The basic law of radiation states that the rate at which radiation is emitted from the solid bed surface in the kiln is given by the following equation:

$$Q_{so} = \sigma A_s \varepsilon_s T_s^{\,4},$$

where the sigma is the Stefan-Boltzmann constant, A_s is the area of the solid bed, ε is the emissivity of the solid bed surface, and T_s is its temperature. When this radiation, Q_{so}, passes through the kiln gas with absorptivity

$$\alpha_{g1} = 1-\tau_{g1},$$

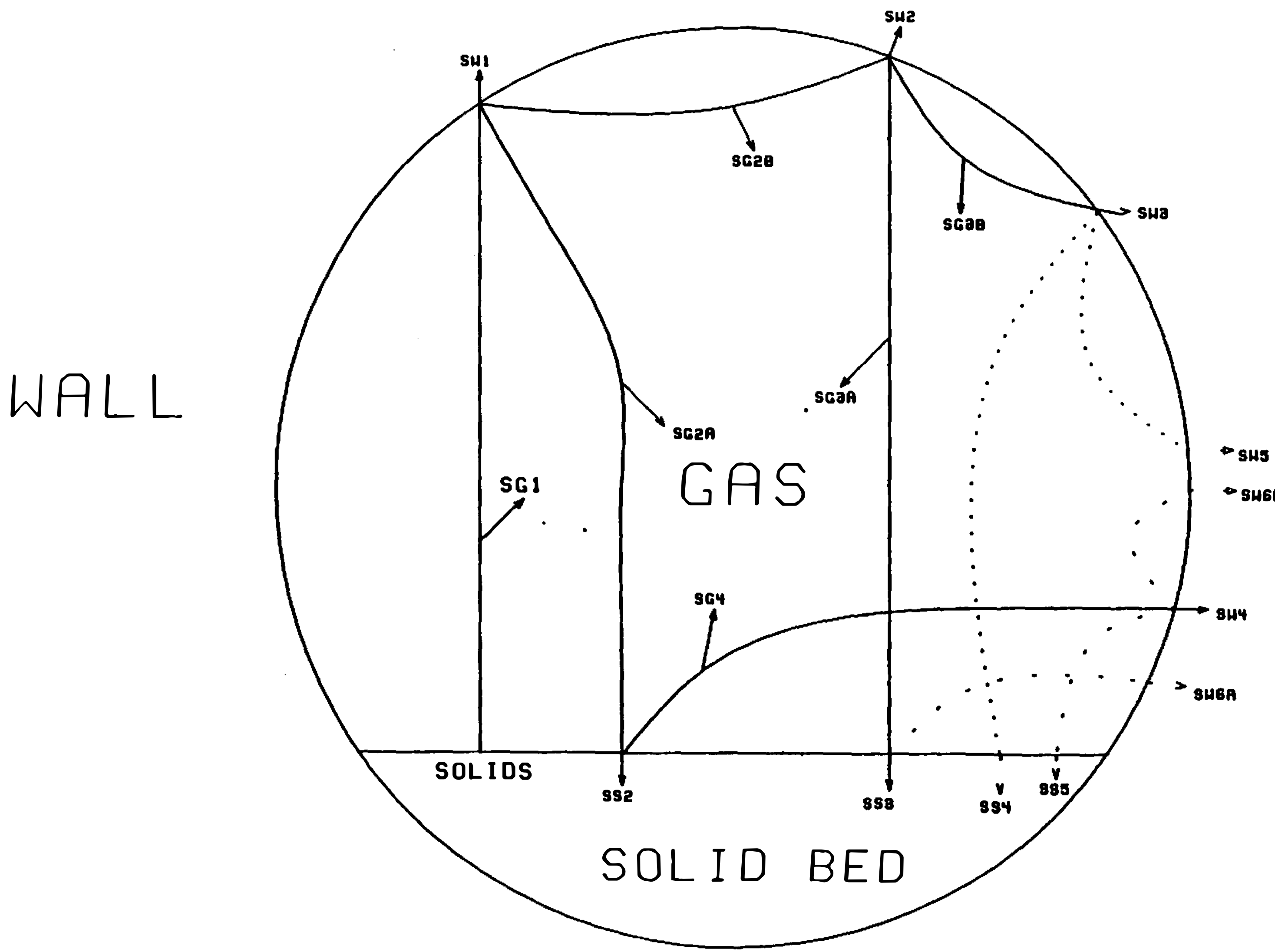


Figure 4.1.4-1. Solid Bed Radiation Drawing w/o Flame

where τ_{g1} is the gas transmissivity for the solid radiation, the rate of absorption is $\alpha_{g1}F_{sw}Q_{so}$ (where α_{g1} is equal to the absorptivity by the gas from the first passage of solid radiation through the gas). When the transmitted radiation hits the wall, the fraction absorbed is α_w and the fraction reflected is ρ_w, or $1-\alpha_w$. Thus the rate of absorption by the wall is

$$GW1 = \alpha_w \tau_{g1} F_{sw} Q_{so}$$

and the rate of reflection is

$$\rho_w \tau_{g1} F_{sw} Q_{so}.$$

When the reflected radiation again traverses the kiln gas space, the fraction transmitted to the solid bed is

$$\tau_{g_2} \rho_w F_{ws} F_{sw} Q_{so}.$$

Therefore the fraction absorbed in this gas path is

$$SG2a = \rho_w F_{ws} F_{sw} Q_{so} (\tau_{g_2} - \tau_{g_1}).$$

τ_{g_2} is greater than τ_{g_1} because some of the radiation frequencies which are absorbed by H_2O and CO_2 have been partially absorbed in the first gas path. After traversing the gas, the radiation again hits the solid bed surface, and is absorbed at the rate

$$SS2 = \alpha_s \rho_w \tau_{g_2} F_{ws} F_{sw} Q_{so}$$

and is reflected (to the wall) at the rate

$$\rho_s \rho_w \tau_{g_2} F_{sw} F_{ws} F_{sw} Q_{so}.$$

Very little of this twice reflected radiation is absorbed by the next gas path,

$$SG4 = (\tau_{g_3} - \tau_{g_2}) \rho_s \rho_w F_{sw} F_{ws} F_{sw} Q_{so},$$

because the gas has absorbed nearly all of the solid radiation which overlaps the real gas spectrum. The rate at which the twice reflected radiation is transmitted through the gas is,

$$\rho_s \rho_w \tau_{g_3} F_{sw} F_{ws} F_{sw} Q_{so}$$

and the fraction absorbed when it collides again with the wall is

$$SW4 = \alpha_w \rho_s \rho_w \tau_{g_3} F_{sw} F_{ws} F_{sw} Q_{so}.$$

For the small remaining fraction (reflected from the wall to the solid bed) the gas is considered to be clear ($\tau_{g_4} = 1$) and the remainder, that is all of the remaining thrice reflected radiation rate is considered to be completely absorbed (α_s=1) by the next solid surface (solid bed) collision,

$$SS5 = \rho_w \rho_s \rho_w \tau_{g_3} F_{ws} F_{sw} F_{ws} F_{sw} Q_{so}.$$

The overall radiation balance for the solid bed may be stated as

$$Q_{so\ \mathrm{emitted}} = Q_{\mathrm{absorbed}}.$$

That is, the rate of energy radiated from the solid bed, Q_{so}, is equal to the sum of the absorption terms including those considered above involving F_{ww}. Stated as an equation:

$$Q_{so} = Q_{sw} + Q_{sg} + Q_{ss}$$

where Q_{sw} includes the energy absorbed by the wall from the initial ray and from its subsequent two reflections from either the bed or from the wall, including the terms involving F_{ww}. Q_{sg} includes three terms corresponding to the three gas passes of the original ray before it is completely absorbed. Q_{ss} includes two absorption terms, one from the first reflection from the wall to the solid, and the other from a second reflection ray which at first had a wall-to-wall reflection.

4.1.5 Equations for the Distribution of Radiation Originating from the Wall and from the Flame

The radiation originating from the wall of the kiln is treated very similar to the way that the solid bed was treated, with similar absorption terms and radiation balance. The listing of these equations are shown in Section 4.2. The luminous character of the flame is due to its content of solid particles (soot and ash) which radiate and absorb radiation like any other solid surface. Therefore the flame, also, is treated in this model as a solid surface, with radiative characteristics similar to those of the solid bed or kiln wall. As will be discussed later in Section 4.3, special provision is made for the partially transparent nature of the flame. Otherwise, the treatment of absorption terms and of the radiation balance is similar to that discussed for radiation originating from the solid bed.

4.1.6 Derivation of Equations for Distribution of Radiation Originating from the Gas

A similar description of the terms required to describe the radiation balance for radiation originating from the gas is given below and listed in Fig. 4.1.6-1. Fewer terms are required to determine the distribution of radiation from the gas to the enclosure due to the high absorptivity of the gas for its own radiation, α'_g. The energy remaining after two reflections of the radiation emitted by the gas is absorbed essentially entirely by the gas. The gas radiates to both the solid bed and

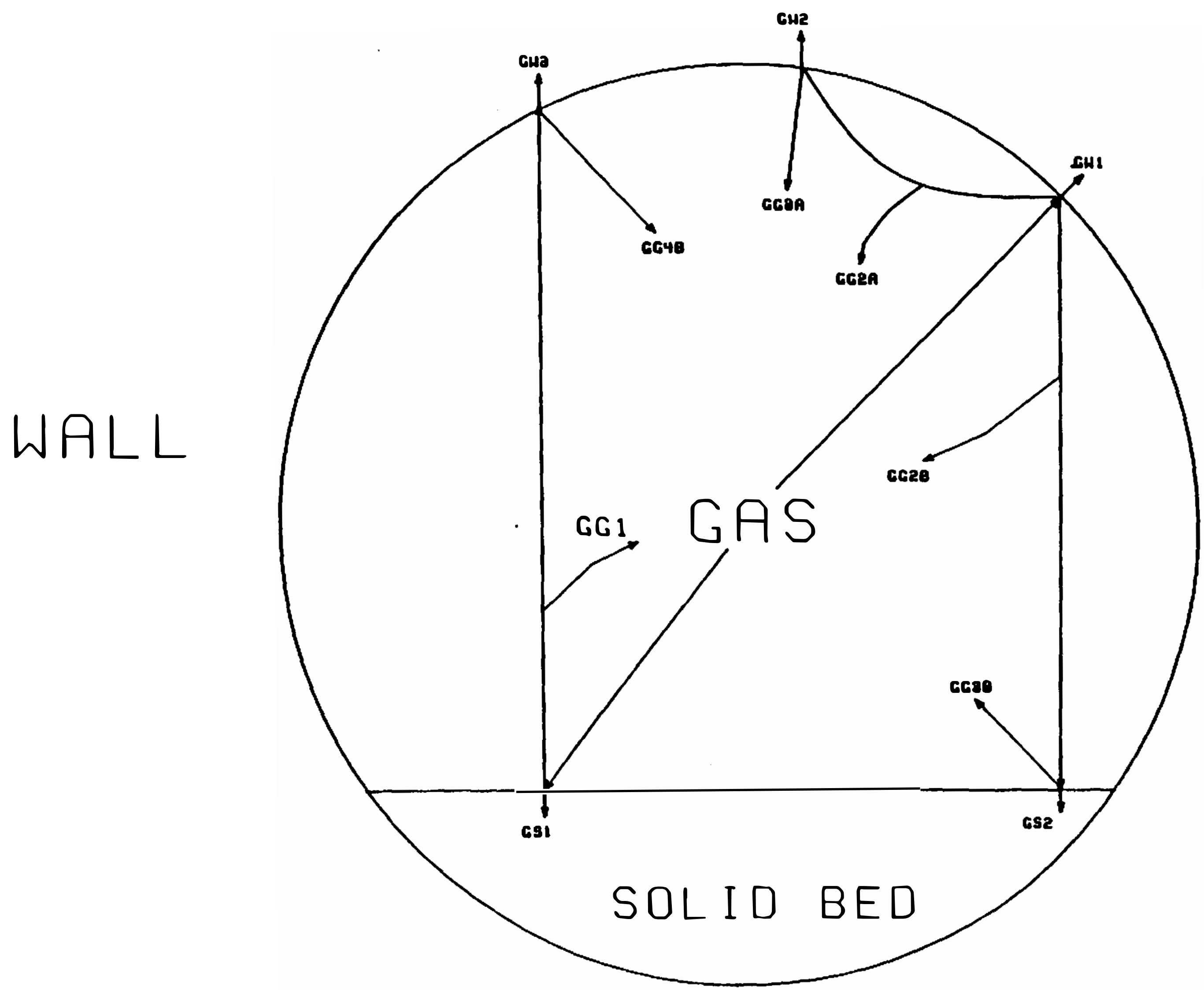


Figure 4.1.6-1. Gas Radiation Drawing w/o Flame

wall. For simplification, only the terms describing the energy radiated to the solid bed will be discussed below. The terms involving the wall are similar in form to those involving the solid bed are are shown in Section 4.2.

The rate at which radiation is emitted from the gas in the kiln, Q_{go}, is given by the equation:

$$Q_{go} = \sigma \varepsilon_g A_g T_g^{\,4},$$

where the sigma is the Stefan-Boltzmann constant, A_g is the total perimeter area of the enclosure, ε_g is the emissivity of the gas, and T_g is its temperature. When this radiation, Q_{go}, strikes the solid bed, the rate of absorption is

$$GS1 = \alpha_s F_{gs} Q_{go}.$$

The fraction reflected is ρ_s, or $1-\alpha_s$. Thus the rate of reflection from the solid bed and starting towards the wall is

$$\rho_s F_{sw} F_{gs} Q_{go}.$$

When the reflected radiation traverses the kiln gas space, a large fraction of the gas radiation is absorbed by the gas, due to the high absorptivity of a real gas for its own radiation. The transmissivity of the gas for its own radiation is given by:

$$\tau'_g = 1-\alpha'_g.$$

The fraction transmitted to the wall is

$$\tau'_g \rho_s F_{sw} F_{gs} Q_{go},$$

therefore the fraction absorbed in this path by the gas is

$$GG1 = (1-\tau'_g)\rho_s F_{sw} F_{gs} Q_{go}.$$

After traversing the gas, the radiation intercepts the wall surface, and is absorbed at the rate

$$GW3 = \alpha_w \rho_s \tau'_g F_{sw} F_{gs} Q_{so}$$

and is reflected (from the wall) at the rate

$$GG4b = \rho_w \rho_s \tau'_g F_{sw} Q_{so}.$$

All of this twice reflected radiation is assumed to be absorbed by the path through the gas due the high absorptivity of the gas for its own radiation. The remaining radiation after two reflections is smaller, and an approximate accounting for this remaining radiation will not affect the results significantly. Similar adsorption terms can be written for the gas radiation which strikes the kiln wall first. The radiation balance equations of the gas for an enclosure with two surfaces is described by Gorog[1] and is similar to the radiation balance for the gas shown in Section 4.2.

4.2 Derivation of Equations for Net Heat Transfer

Previous Work -

As illustrated in Sections 4.1.1 through 4.1.6 for the simplified (no flame) case, the method estimates how the radiated energy, Q_i in Eqn. 4.1-1, is distributed to the gas and the surfaces (including itself) in the enclosure as a function of the surface and gas temperatures, areas, emissivities and absorptivities, and geometrical relationships (view factors) in the enclosure.

The heat absorbed by a surface i may be summarized by

$$Q_{i\ \mathrm{absorbed}} = Q_{gi} + \sum_{j=1,n} Q_{ji} \qquad \text{(Eq. 4.2-1)}$$

[Total heat absorbed by surface i]	=	[heat absorbed by surface i from the gas]	+	[heat absorbed by surface i from other surfaces j]

The net radiant heat change for a surface (or the gas), ΔQ_i, is the difference between heat emitted and heat absorbed:

$$\Delta Q_{\text{gained or lost}} = Q_{\text{emitted}} - Q_{\text{absorbed}} \qquad \text{(Eq. 4.2-2)}$$

Therefore,

$$\Delta Q_i = Q_i - (Q_{gi} + {}_{j=1,n}\, Q_{ji}) \qquad \text{(Eq. 4.2-3)}$$

These relationships are shown in Fig. 4.2-1 for the radiation from the solid bed, wall, gas, and flame.

Applying Eq. 4.2-4 to Gorog's model, which contained only two surfaces (wall and solid bed), the gas, <u>and no flame</u>, results in the following equations:

$$\Delta Q_s = Q_s - (Q_{ss} + Q_{ws} + Q_{gs})$$
$$\Delta Q_w = Q_w - (Q_{sw} + Q_{ww} + Q_{gw})$$
$$\Delta Q_g = Q_g - (Q_{sg} + Q_{wg} + Q_{gg}),$$

where the subscripts s,w, and g represent solid, wall, and gas respectively. An absorption term such as Q_{ws} represents the radiation absorbed by the solid bed (s) from radiation originating from the wall (w). As illustrated in Section 4.1.1 and Section 4.1.3 each absorption term in these equations is determined by tracing the emission from each surface through two reflections. Each term Q_{ij} is the energy originally emitted by surface i which is absorbed by surface j and is defined by the sum of

(1) the fraction of radiation initially emitted from surface i which is absorbed by surface j during two reflections, and

(2) the fractions of the remaining reflection after two reflections which is assumed by the model to be absorbed by surface j.

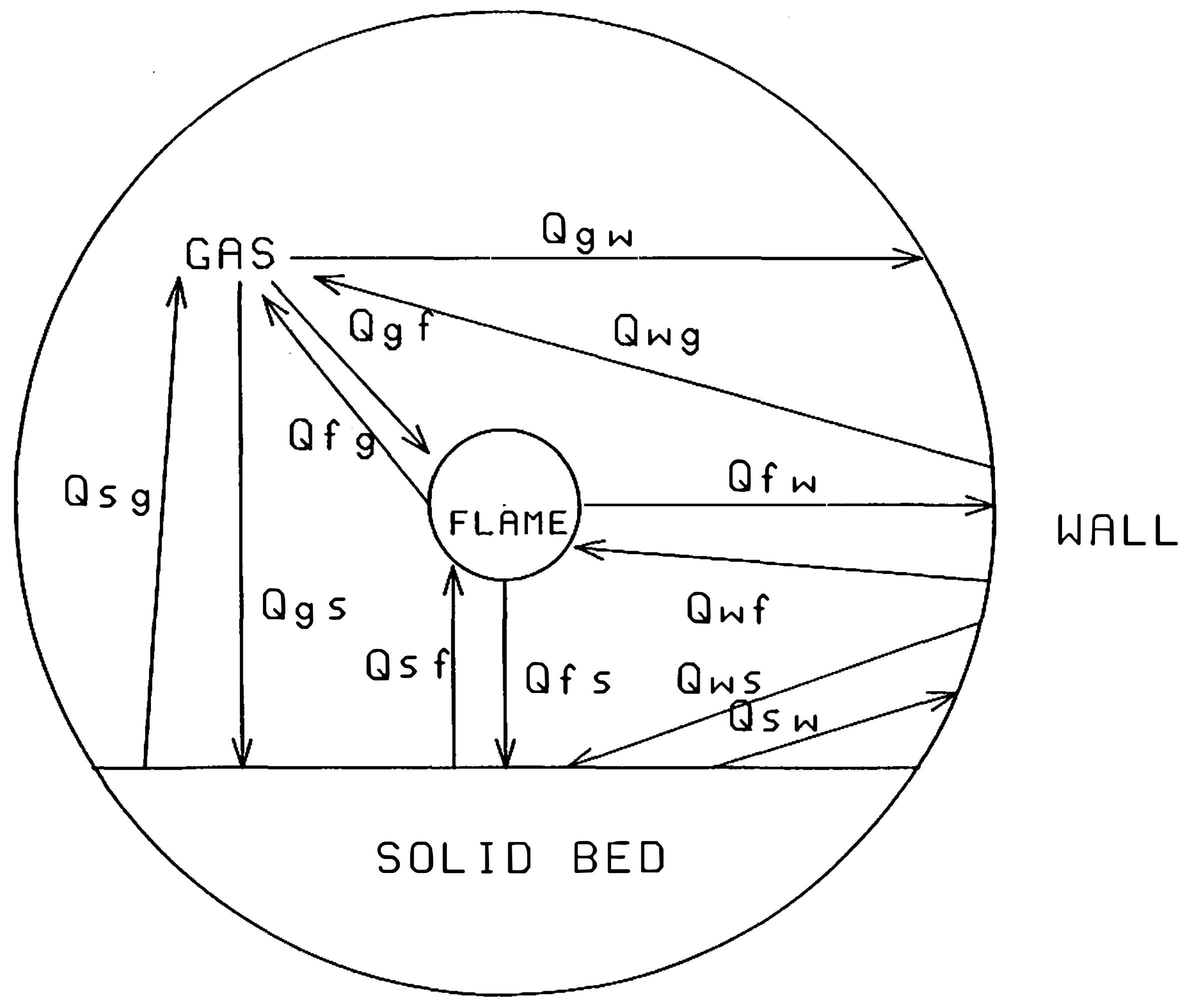


Figure 4.2-1. **Crossection of kiln with Overall Heat Transfer Equations**

The term Q_{ig} is the energy originally emitted by surface i which is absorbed by the gas and is defined by the sum of (1) the fraction initially emitted from surface i which is absorbed by the gas, and (2) the fraction of the originating ray's reflections which are absorbed by the gas. The resulting set of equations defines the radiation balance for the kiln. The determination of these terms is discussed further in Section 4.1.

Current Work -

The kiln model as presented by Gorog is modified in the present work by dividing Gorog's single section kiln into a number of 1.5 foot long sections and by the addition of the flame as a third surface in the flame region. For each 1.5 foot long section in the gas region downstream of the flame, the radiation balance developed by Gorog for 2 surfaces and a gas is used. The neglect of axial radiation and end effects is shown later in Section 4.3 to result in a tolerable error. A further modification of Gorog's model was to treat the kiln gases as a real gas (see Section 4.4). Each 1.5 foot long section of the kiln is treated as a separate radiation enclosure with uniform (but not equal) temperatures T_i in the wall, gas, and solids.

The addition of the flame surface as a third surface in the flame region complicates the radiation balance. For each 1.5 foot long section of the flame region, the net radiation absorbed or emitted is determined by the following equations:

$$\Delta Q_s = Q_s - (Q_{ss} + Q_{ws} + Q_{gs} + Q_{fs})$$

$$\Delta Q_w = Q_w - (Q_{sw} + Q_{ww} + Q_{gw} + Q_{fw})$$

$$\Delta Q_g = Q_g - (Q_{sg} + Q_{wg} + Q_{gg} + Q_{fg})$$

$$\Delta Q_f = Q_f - (Q_{sf} + Q_{wf} + Q_{gf} + Q_{ff})$$

It is seen that the addition of the flame surface added a fourth equation, as well as an additional term in each of the equations.

The radiation balance could be extended, if necessary, to consider more surfaces, such as the end surfaces of the kiln. The treatment would be similar to that indicated for the added flame surface. For each added solid surface, there would be the added complication that its presence would affect each of the other absorption terms such as Q_{ws}. Radiation originating from surface w may be reflected from the added surface before being absorbed by surface s. Therefore, the presence of the added surface would affect the values of Q_{ws}.

The complete radiation reflection diagrams and the associated equations are shown in Figs. 4.2-2, 4.2-3, 4.2-4, 4.2-5, and 4.2-6 for the radiation emitted by the solid bed, wall, flame, and gas. Figure 4.2-6 presents a print of functions from the portion of the spreadsheet program which calculates the heat transfer in a zone of the kiln. As indicated in the figures, the presence of the additional flame surface complicates the radiation balance considerably.

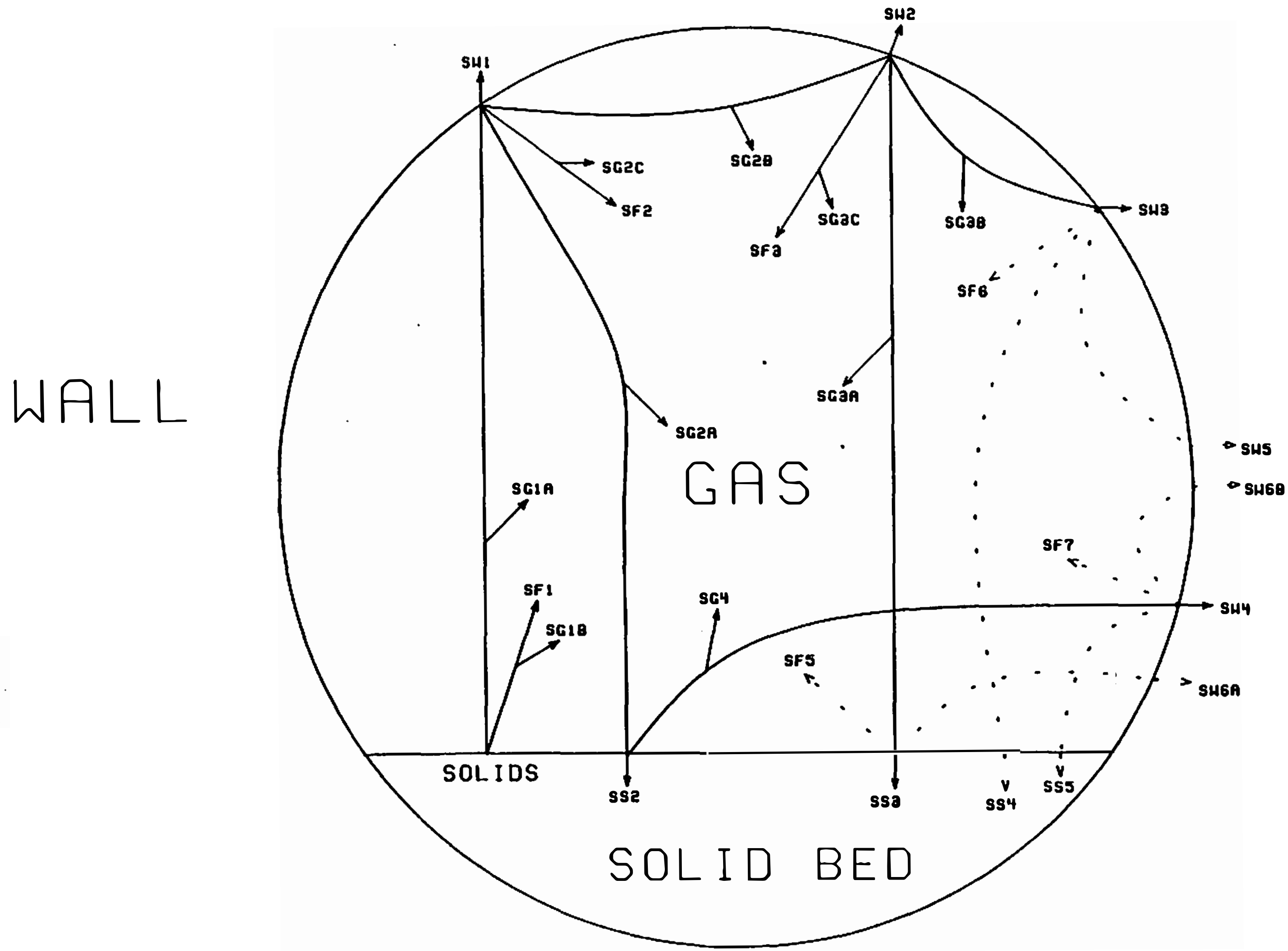


Figure 4.2-2. Solid Bed Radiation Drawing

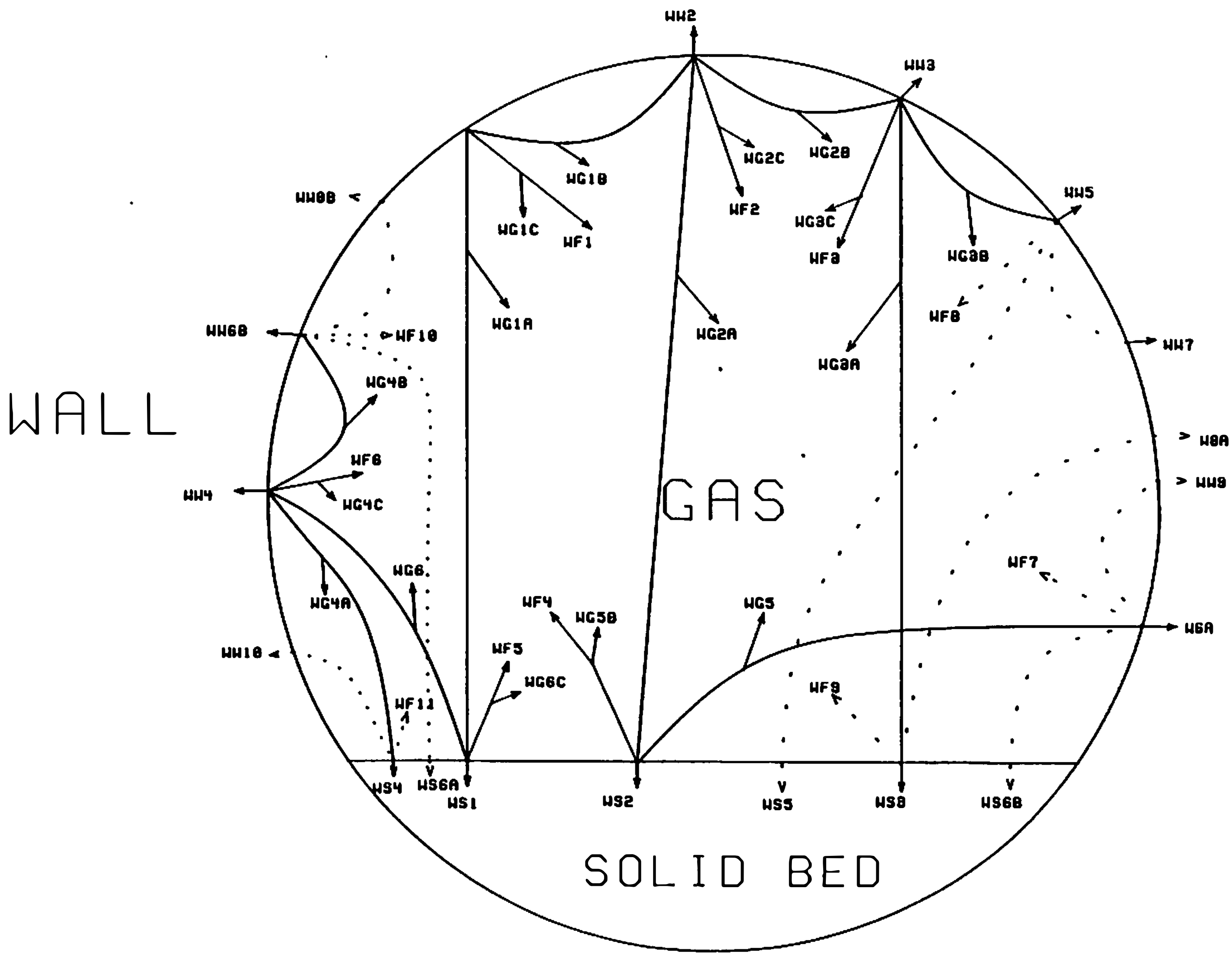


Figure 4.2-3. Wall Radiation Drawing

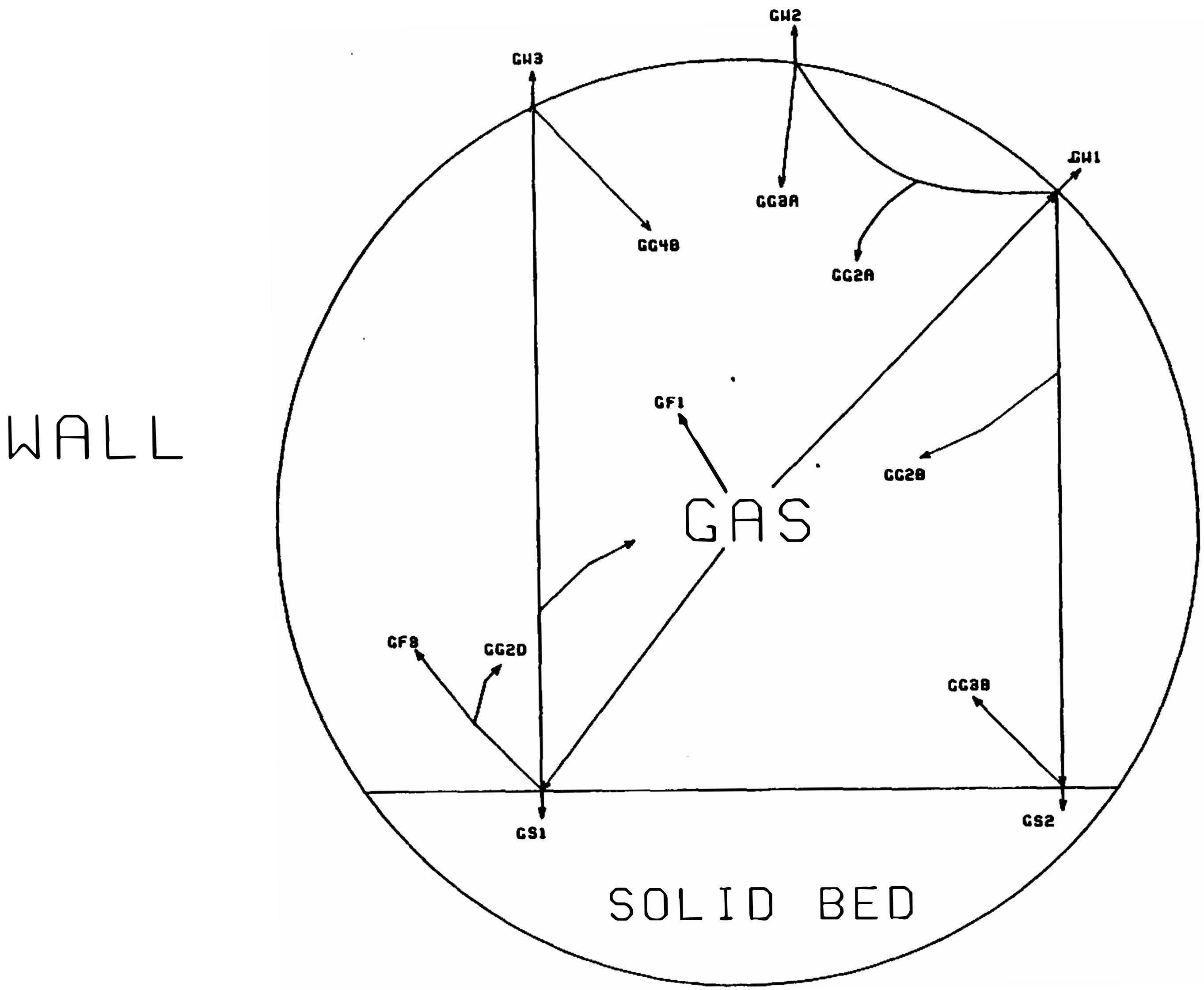


Figure 4.2-4. Gas Radiation Drawing

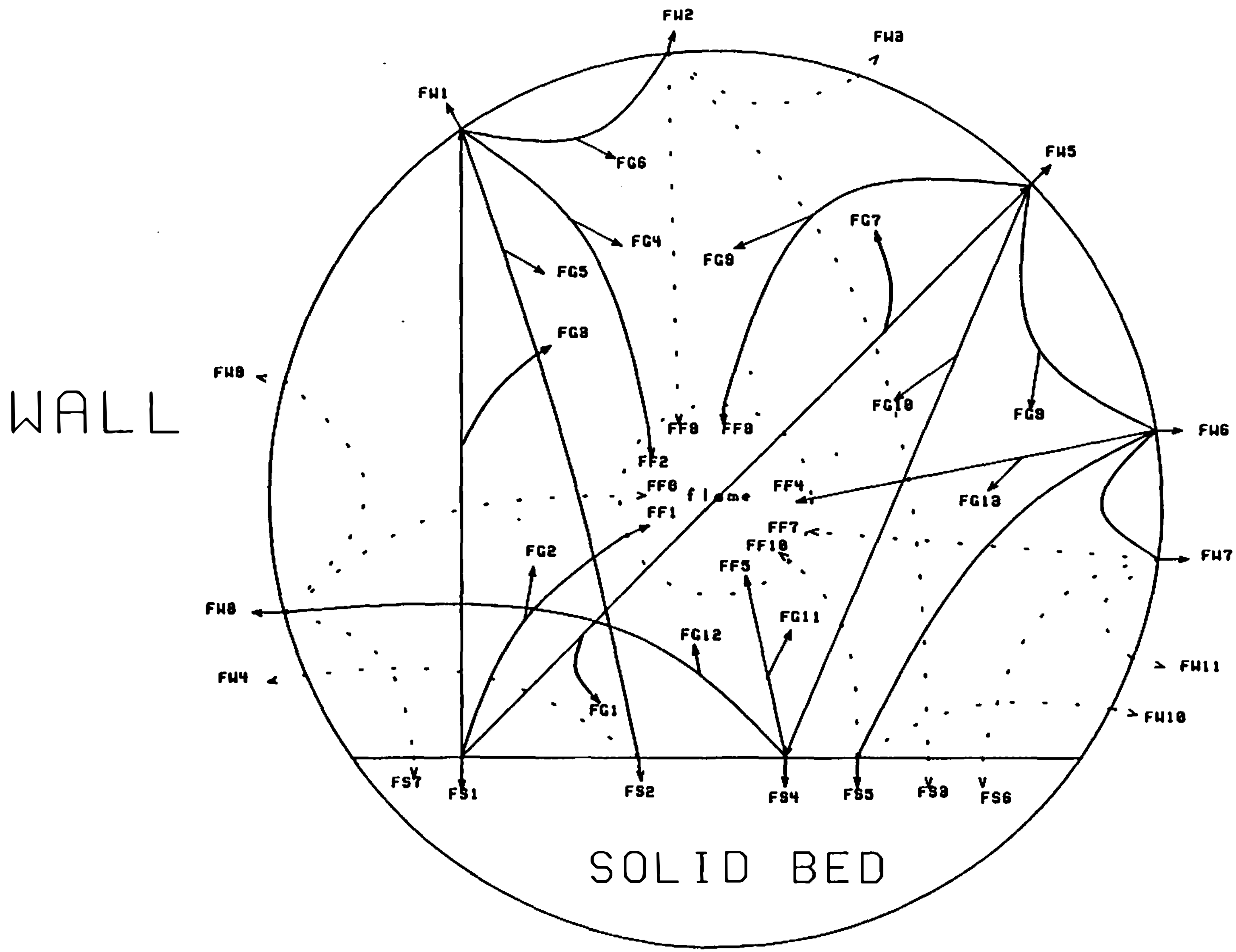


Figure 4.2-5. Flame Radiation Drawing

Qs = ssEs + wsEw + gsEg + fsEf + hcvws(Tw - Ts) + hcvgs(Tg - Ts)

Qw = swEs + wwEw + gwEg + fwEf + hcvgw(Tg - Tw) - hcdwsh(Tw - Tsh)

Qg = sgEs + wgEw + ggEg + fgEf - hcvgs(Tg - Ts) + hcvgw(Tg - Tw

Qf = sfEs + wfEw + gfEg + ffEf

FLF =	0.80
EMs =	0.80
EMw =	0.80
EMf =	1.00

					Watts	BTU/HR
Es	ss	1	EMs*As	0.3308		
		2	-ABs*TRgs2*Fws*Fsw*pw*EMs*As	-0.0043		
		3	-ABs*TRgs3*Fws*Fww*Fsw*pw*pw*EMs*As	-0.0004		
		4	-Fws*TRgs3*Fww*Fww*Fsw*pw*pw*pw*EMs*As	-0.0001		
		5	-Fws*TRgs3*Fws*Fsw*Fsw*ps*pw*pw*EMs*As	0.0000		
Qs <= Qs				0.3259	15,924	54,364
Ew	ws	1	-ABs*TRgw1*Fws*EMw*Aw	-0.1463		
		2	-ABs*TRgw2*Fws*Fww*pw*EMw*Aw	-0.0140		
		3	-ABs*TRgw3*Fws*Fww*Fww*pw*pw*EMw*Aw	-0.0014		
		4	-ABs*TRgw3*Fws*Fws*Fsw*ps*pw*EMw*Aw	-0.0006		
		5	-Fws*TRgw3*Fww*Fww*Fww*pw*pw*pw*EMw*Aw	-0.000178		
		6	-2*Fws*TRgw3*Fws*Fww*Fsw*ps*pw*pw*EMw*Aw	-0.0002		
Qs <= Qw				-0.1626	(37,509)	(128,056)
Eg	gs	1	-ABs*EMg*As	-0.0835		
		2	-ABs*Fws*pw*TRgs11*EMg*Aw	-0.0029		
Qs <= Qg				-0.0864	(4,000)	(13,656)
Ef	fs		-ABs*TRgf1*Ffs*EMf*Af	-0.0972		
		2	-ABs*TRgf3*ps*pw*Ffs*Fsw*Fws*EMf*Af	-0.0004		
		3	-TRgf3*ps*pw*pw*Ffs*Fsw*Fww*Fws*EMf*Af	-0.0001		
		4	-ABs*TRgf2*pw*Ffw*Fws*EMf*Af	-0.0116		
		5	-ABs*TRgf3*pw*pw*Ffw*Fww*Fws*EMf*Af	-0.0012		
		6	-TRgf3*pw*pw*pw*Ffw*Fww*Fww*Fws*EMf*Af	-0.0002		
		7	-TRgf3*pw*pw*ps*Ffw*Fws*Fws*Fsw*EMf*Af	-0.0001		
				-0.1106	(50,425)	(172,150)
	hcvws		+hcvws*(THIrad*D/2)*(Tw-Ts)	12627	(12,627)	(43,108)
	hcvgs		+hcvgs*As*(Tg-Ts)	-107	107	366
					*********	
Qs =>					(88,529)	(302,238)
						72

Figure 4.2-6. Radiation Balance Equations

```
       Qw
       *************************************************************

       sw    1 -ABv*TRgs1*Fsw*EMs*As                              -0.1330
             2 -ABv*TRgs2*Fvv*Fsv*pv*EMs*As                       -0.0128
Es           3 -ABv*TRgs3*Fvv*Fvv*Fsv*pv*pv*EMs*As                -0.0012
             4 -ABv*TRgs3*Fvs*Fsv*Fsv*ps*pv*EMs*As                -0.0005
             5 -Fvv*TRgs3*Fvv*Fvv*Fsv*pv*pv*pv*EMs*As           -0.000160
             6 -2*Fvv*TRgs3*Fvs*Fsv*Fsv*ps*pv*pv*EMs*As           -0.0001
Qw <- Qs                                                          -0.1479   (7,224) (24,664)

       ww    1 +EMv*Aw                                             1.2574
Ew           2 -ABv*TRgv1*Fvv*EMv*Aw                              -0.4314
?*Fvv        3 -ABv*TRgv2*Fvv*Fvv*pv*EMv*Aw                       -0.0414
             4 -ABv*TRgv2*Fvs*Fsv*ps*EMv*Aw                       -0.0181
             5 -ABv*TRgv3*Fvv*Fvv*Fvv*pv*pv*EMv*Aw                -0.0040
             6 -2*ABv*TRgv3*Fvs*Fvv*Fsv*ps*pv*EMv*Aw              -0.0035
             7 -Fvv*TRgv3*Fvv*Fvv*Fvv*pv*pv*pv*EMv*Aw             -0.0005
             8 -2*Fvv*TRgv3*Fvs*Fvv*Fsv*ps*pv*pv*EMv*Aw           -0.0005
             9 -Fsv*TRgv3*Fvv*Fvv*Fvs*ps*pv*pv*EMv*Aw             -0.0002
            10 -Fsv*TRgv3*Fvs*Fvs*Fsv*ps*ps*pv*EMv*Aw             -0.0001
Qw <- Qw                                                           0.7576  174,743  596,574

Eg     gw    1 -ABv*EMg*Aw                                        -0.3175
             2 -ABv*Fvv*pv*TRgv11*EMg*Aw                          -0.0086         ?
             3 -ABv*Fsv*ps*TRgv11*EMg*As                          -0.0029
Qw <- Qg                                                          -0.3290  (15,225) (51,977)

Ef     fw    1 -ABv*TRgf2*ps*Ffs*Fsv*EMf*Af                       -0.0126
             2 -ABv*TRgf3*ps*pv*Ffs*Fsv*Fvv*EMf*Af                -0.0013
             3 -TRgf3*ps*pv*pv*Ffs*Fsv*Fvv*Fvv*EMf*Af             -0.0002
             4 -TRgf3*ps*ps*pv*Ffs*Fsv*Fsv*Fvs*EMf*Af             -0.0001
             5 -ABv*TRgf1*Ffv*EMf*Af                              -0.3402
             6 -ABv*TRgf2*pv*Ffv*Fvv*EMf*Af                       -0.0342
             7 -ABv*TRgf3*pv*pv*Ffv*Fvv*Fvv*EMf*Af               -0.00344
             8 -ABv*TRgf3*pv*ps*Ffv*Fvs*Fsv*EMf*Af                -0.0015
             9 -TRgf3*pv*pv*ps*Ffv*Fvs*Fsv*Fvv*EMf*Af             -0.0002
            10 -TRgf3*pv*pv*ps*Ffv*Fvv*Fvs*Fsv*EMf*Af             -0.0002
            11 -TRgf3*pv*pv*pv*Ffv*Fvv*Fvv*Fvv*EMf*Af             -0.0004
                                                                  -0.3942 (179,652)(613,333)

       hcvws  +hcvws*(THIrad*D/2)*(Tw-Ts)                           12627   12,627   43,108
       hcvgw  +hcvgw*Aw*(Tg-Tw)                                     -7382    7,382   25,204
       hcdwsh +hcdwsh*area3*(Tw-Tsh)                                 7346    7,346   25,080
                                                                          *********
Qw ->                                                                         (2)      (8)
```

Figure 4.2-6. (continued)

```
          Qg
          ***********************************************************************

Es    sg    1 -(1-TRgs1)*EMs*As                                   -0.0829
            2 -(TRgs1-TRgs2)*Fsw*pw*EMs*As                        -0.0026
            3 -(TRgs2-TRgs3)*Fww*Fsw*pw*pw*EMs*As                 -0.0002
            4 -(TRgs2-TRgs3)*Fws*Fsw*ps*pw*EMs*As                 -0.0001
Qg <- Qs                                                          -0.0858   (4,192) (14,311)

Ew    wg    1 -(1-TRgw1)*EMw*Aw                                   -0.2213
            2 -(TRgw1-TRgw2)*Fww*pw*EMw*Aw                        -0.0085
            3 -(TRgw2-TRgw3)*Fww*Fww*pw*pw*EMw*Aw                 -0.0007
            4 -(TRgw2-TRgw3)*Fws*Fsw*ps*pw*EMw*Aw                 -0.0003
            5 -(TRgw2-TRgw3)*Fws*Fww*ps*pw*EMw*Aw                 -0.0002
            6 -(TRgw1-TRgw2)*Fws*ps*EMw*Aw                        -0.0029
Qg <- Qw                                                          -0.2338   (53,917)(184,072)

Eg    gg    1 +EMg*Ag                                              0.6559
            2 -ABg11*pw*EMg*Aw                                    -0.0587
            3 -(+pw*Fww+ps*Fws)*pw*TRg11*EMg*Aw                   -0.0029
            4 -(+ABg11+pw*TRg11)*Fsw*ps*EMg*As                    -0.0111
Qg <-      2a -ABg11*ps*Fsf*As*EMg                                -0.0051
                                                                   0.5781    26,752    91,332

Ef    fg    1 -(1-TRgf1)*EMf*Af                                   -0.0657
            2 -(TRgf1-TRgf2)*ps*Ffs*EMf*Af                        -0.0008
            3 -(TRgf2-TRgf3)*ps*pw*Ffs*Fsw*EMf*Af                 -0.0001
            4 -(TRgf1-TRgf2)*pw*Ffw*EMf*Af                        -0.0029
            5 -(TRgf2-TRgf3)*pw*ps*Ffw*Fws*EMf*Af                 -0.0001
            6 -(TRgf2-TRgf3)*pw*pw*Ffw*Fww*EMf*Af                 -0.0003
                                                                  -0.0699   (31,869)(108,800)

      hcvgs  +hcvgs*As*(Tg-Ts)                                      -107     (107)     (366)
      hcvgw  +hcvgw*Aw*(Tg-Tw)                                     -7382   (7,382)  (25,204)
                                                                            *********
Qg ->                                                                       (70,715)(241,421)
```

Figure 4.2-6. (continued)

```
Qf
*************************************************************************

Es     sf    1 -TRgs1*Fsf*EMs*As                                 -0.0816
             2 -TRgs2*pw*Fsw*Fwf*EMs*As                          -0.0093
Qf <-        3 -TRgs3*pw*pw*Fsw*Fww*Fwf*EMs*As                   -0.0009
             4 -TRgs3*pw*ps*Fsw*Fws*Fsf*EMs*As                   -0.0003
             5 -Fww*TRgs3*Fws*Fsf*Fsw*ps*pw*pw*EMs*As             0.0000
             6 -Fwf*TRgs3*Fww*Fww*Fsw*pw*pw*pw*EMs*As            -0.0001
             7 -Fwf*TRgs3*Fws*Fsw*Fsw*ps*pw*pw*EMs*As             0.0000
                                                                 -0.0923   (4,508) (15,389)

Ew     wf    1 -TRgw1*Fwf*EMw*Aw                                 -0.3140
             2 -TRgw2*pw*Fww*Fwf*EMw*Aw                          -0.0301
             3 -TRgw3*pw*pw*Fww*Fww*Fwf*EMw*Aw                   -0.0029
Qf <-        4 -TRgw3*pw*ps*Fww*Fws*Fsf*EMw*Aw                   -0.0011
             5 -ps*TRgw2*Fws*Fsf*EMw*Aw                          -0.0111
             6 -TRgw3*ps*pw*Fws*Fsw*Fwf*EMw*Aw                   -0.0013
             7 -Fsw*TRgw3*Fwf*Fww*Fws*ps*pw*pw*EMw*Aw            -0.0001
             8 -Fwf*TRgw3*Fww*Fww*Fww*pw*pw*pw*EMw*Aw            -0.0003
             9 -Fww*TRgw3*Fws*Fww*Fsf*ps*pw*pw*EMw*Aw            -0.0001
            10 -Fwf*TRgw3*Fws*Fww*Fsw*ps*pw*pw*EMw*Aw            -0.0001
            11 -Fsf*TRgw3*Fws*Fws*Fsw*ps*ps*pw*EMw*Aw             0.0000
                                                                 -0.3612  (83,318)(284,447)

Eg     gf    1 -Af*EMg                                           -0.1546
             2 -TRgf11*pw*Fwf*Aw*EMg                             -0.0063
Qf <-        3 -TRgf11*ps*Fsf*As*EMg                             -0.0018
                                                                 -0.1627   (7,527) (25,698)

Ef     ff    1 +EMf*Af                                            0.6124
             2 -TRgf2*ps*Fsf*Ffs*EMf*Af                          -0.0077
             3 -TRgf3*ps*pw*Ffs*Fsw*Fwf*EMf*Af                   -0.0009
Qf <-        4 -TRgf2*pw*Ffw*Fwf*EMf*Af                          -0.0249
             5 -TRgf3*pw*pw*Ffw*Fww*Fwf*EMf*Af                   -0.0025
             6 -TRgf3*pw*ps*Ffw*Fws*Fsf*EMf*Af                   -0.0009
             7 -TRgf3*pw*pw*pw*Ffw*Fwf*Fww*Fww*EMf*Af            -0.0003
             8 -TRgf3*pw*pw*ps*Ffw*Fws*Fsw*Fwf*EMf*Af            -0.0001
             9 -TRgf3*ps*pw*pw*Ffs*Fsw*Fww*Fwf*EMf*Af            -0.0001
            10 -TRgf3*pw*pw*ps*Ffw*Fww*Fws*Fsf*EMf*Af            -0.0001
            11 -TRgf3*ps*ps*pw*Ffs*Fsw*Fsf*Fws*EMf*Af             0.0000
                                                                  0.5748  261,946  894,283
Qf ->                                                           ***************************
                                                                          166,593  568,749

*********************************************************************************

             Qs =                                                         (88,529)(302,238)
             Qw =                                                              (2)      (8)
             Qg =                                                         (70,715)(241,421)
                                        Qf =                               166,593  568,749
*********************************************************************************
```

Figure 4.2-6. (continued)

4.3 <u>The Effect of Neglecting Axial Radiation and End Effects</u>

<u>Previous Work</u> -

Two simplifying assumptions used in the Resistive Network radiation model as presented by Gorog and Brimacombe which have been included in the present model are important to note: (1) The effects of axial radiation are neglected, and (2) the effects of radiation from the end surfaces of the kiln have been neglected. These simplifications are made to avoid calculational difficulties associated with including these effects when the kiln is divided into sections as is done in Resistive Network Method, and in the present work. The Zone method also divides the kiln into sections, but generally considers both of these effects.

The second simplification is considered to be reasonable because the surface areas of the ends of most kilns are small compared to the areas of the wall and solid bed, and are reported to not contribute significantly to the overall heat transfer in the kiln[2,3]. Including the kiln ends in the model would principally affect heat transfer in the first and last zones of the kiln. The effect can be crudely thought of as increasing the wall surface area in those zones.

Axial radiation refers to the effect of radiation from the gas and surfaces in one section radiating to the gas and surfaces in other sections of the kiln. Consideration of this effect is omitted in the present work. The effect of this omission has been studied by Gorog for a 300°K/M flame temperature gradient and is reported to result in at most a 20%

error[3] for the cases they considered. This neglect of axial radiation effect is reasonable if the temperature gradient between sections is not large, because the radiation gained from adjacent sections largely compensates for the axial radiation lost from a given section to adjacent sections in the kiln. The effects of axial radiation have been shown to be negligible for distances beyond 3/4 of a kiln diameter[1]. The radiation from the gas has a high absorptivity for its own radiation, and axial radiation from the gas is quickly reabsorbed by the gas in the same section. The beam length for gas radiation used in the present calculations is approximately 1/2 the kiln diameter (see Section 4.4) which also limits the effect of axial radiation from the gas.

Both of these effects would tend to increase the gas temperature and lower the flame temperature in the flame region of the kiln. These effects are less important in the downstream gas region of the kiln due to the relatively smaller temperature gradient between sections in the gas region and the larger distance from the front end of the kiln.

Current Work -

The effect of radiation from an end of the kiln to its adjacent section could be treated in the model by including the end of the kiln as a fourth surface in the balance. However, considering axial radiation would significantly increase the calculational difficulty involved in determining the temperature profile of the kiln, requiring an additional trial and error process using assumed temperatures for the adjacent sections of the kiln. An additional set of view factors would have to be calculated for each of the adjacent sections considered. (If axial radiation from only the immediately adjacent sections were considered, one additional set of view factors would be required). In view of the considerable added computational difficulties from including the effects of end surface and axial radiation, and cited information that neglecting these effects would provide only marginal improvement in the results, it was decided to neglect these effects in the present study.

4.4 Radiation Model of the Flame

Previous Work -

As discussed earlier (Section 3.2 and 3.3), an accurate prediction of the flame behavior must be based on the experimental measurement of the effects of factors such as flame temperature, flame length, flame emissivity, flame shape, etc. Such modeling based on detailed experimental data has been done by Jenkins[4] and Johnson[5]. Where data are not available, the flame emissivity is treated as a gray or black body of constant emissivity and the shape of the flame is treated as an axial symmetric cylinder of a constant diameter[3] or as a cone with diameter increasing with axial distance from the burner[4,5].

Current Work -

The Reflection Method can in theory be applied to as many surfaces as needed to model an enclosure, however, the number of equations required increases greatly with each increase in the number of surfaces. The addition of the flame to the radiation balance as a third solid surface doubles the number of equations to represent the emissions, reflections, and absorption of radiant energy required to predict the radiant heat transfer in the flame region. The flame was modeled as a solid surface which approximated a semi-transparent medium such as the gas. Gorog[1] presented the radiative balance with only two surfaces (the kiln wall and solid bed) and the gas. The presence of a flame is an important factor in a heat transfer model due to its high temperature and high emissivity as compared to the gas, and significantly increases the heat transferred to the solid bed and wall of the kiln. Without a flame much less heat is transferred. This treatment results in an entirely different temperature profile of the flame region. The effect of this treatment is described further in the discussion of the results.

In the present calculations, the flame is modeled as an axial cylinder of constant diameter. The flame surface is different from the gray solid surfaces of the solid bed and wall because some of the radiation is transmitted through the flame, and essentially no radiation is reflected. The flame is treated as a black body of reduced crossectional area. The reduced area core of the flame is treated as a solid black body (which does not reflect radiation) and radiation transmission can take place through the additional gas volume made available by the reduction of flame diameter. This reduction of flame area is made in such a way that the product of the black body emissivity

(ε=1) times the reduced area is equal to the original emissivity times the unreduced area. This treatment of the flame is an innovation of this study and has not been discussed previously in the literature. This relationship causes the original area and emissivity of the flame to be changed to a new 'effective' area (A'_f) and emissivity (ε'_f=1) in the equation for radiant heat from the flame to another surface (s) in the kiln becomes

$$q_{f->s} = \sigma A_f \varepsilon_f F_{fs} T_f^4$$
$$q_{f->s} = \sigma A'_f \varepsilon'_f F_{fs} T_f^4$$

The relative view factors from the flame to the other surfaces do not change because of the axial symmetry of the flame.

The reduced area of the flame causes a reduction of the operative view factors (F'_{sf}) for the surface to the flame which determines the fraction of radiation emitted by the surface which is seen by the flame. This reduction compensates for the energy that would have been transmitted through the flame if it were a gray (translucent) body. The radiation for a kiln surface (s) radiating to the flame (f) is given by the equation:

$$q_{s->f} = \sigma A_s \varepsilon_s F'_{sf} T_s^4$$

Treating the emitting flame as a black body of reduced area is equivalent to considering it as a gray body with its actual area. The result is less absorption and emission by the flame, as if it were a gray body. This treatment greatly simplifies the calculation of the radiation balance. Treating the flame as a gray body would double the number of equations required to calculate the flame radiation absorbed by the gas and surfaces in the kiln. The additional equations would account for radiation which passed through the flame. The mathematical details of this treatment of the flame are described in Appendix C.

4.5 Emissivity Characteristics of the Gas

Previous Work -

The freeboard gases common to a direct-fired rotary kiln operation are composed mainly of CO_2-H_2O mixtures in nitrogen resulting from the combustion of hydrocarbons fuels and moisture from the solid bed and air. These gases emit and absorb radiation in discrete frequency bands. The absorptivity and emissivity of the gas need not be equal or constant (as they are considered in the Resistive Method) and are functions of the gas temperature, composition, and beam length (the gas is not a gray body). Absorptivity is also a function of the wavelength distribution of the incident radiation and thus of the emitting surface temperature.

The mean beam length, L_m, is an approximate representation of the geometry of an isothermal gas volume. Physically, the mean beam length is the radius of an equivalent gas hemisphere which radiates a flux to the center of its base equal to the average flux radiated to the area of interest by the actual volume of gas. The emissivity of a gas is generally modeled as a gray gas or gray/clear gas. For a gray gas model, the emissivity is equal to the absorptivity of the gas, and it is not considered to be a function of the temperature of the solids, the gas composition, or the gas temperature. The resistive network method is limited to this type of treatment of the gas emissivity[20]. The error introduced by this approximation may be greater than 20%, depending on the reflectivity of the surrounding solids (Gorog)[1].

The 'gray/clear' gas model, initially proposed by Hottel and Cohen[17], attempts to model a real gas more closely. Hottel and Sarofim[16] suggest that gas radiation can be represented as the weighted sum of a sufficient number of gray and clear gas components to approximate the banded characteristics of a real gas. The accuracy of this model increases with the number of gray or clear components used. The model is generally developed for a combustion gas of a fixed composition which is equimolar in CO_2 and H_2O. However, additional water is introduced during the kiln operation due to the presence of moisture from the solid bed and water in the air (humidity). This variation of moisture concentration during kiln operation reduces the accuracy of the gray/clear gas model.

In Hottel's method[16], the absorptivities of water vapor and CO_2 are estimated by the following formula respectively:

$$\alpha_{H_2O} = \varepsilon_{H_2O\,Ts,(pL_mT_s/T_g)} (T_g/T_s)^{.45}$$

$$\alpha_{CO_2} = \varepsilon_{CO_2\,Ts,(pL_mT_s/T_g)} (T_g/T_s)^{.65}$$

and,

$$\varepsilon_g = (\varepsilon_{g_{CO_2}} + \varepsilon_{g_{H_2O}})(1-C_{so})$$

$$\alpha_g = (\alpha_{g_{CO_2}} + \alpha_{g_{H_2O}})(1-C_{so})$$

The formula for α_g has been used by Johnson[25] with the exponent of 0.5 to provide an approximate value for absorptivity of combustion product gases.

<u>Current Work</u> - <u>Emissivity of CO_2 and H_2O</u>

In the present work the gas emissivity of CO_2 and water was calculated using Hottel's data[16] for emissivity. Hottel's data were regressed using a least squares method which enabled emissivity of any partial pressure of CO_2 and H_2O to be calculated for a wide range of temperatures and beam lengths. The data regression was carried out using the computer program listed in Appendix G. The average beam length, L_m, of the gas used in the present work was calculated using the following formula:

$$L_m = [\pi/(4(2)^{1/2})]D(1-FD)$$

$$L_m = 0.55D(1-FD)$$

where F is equal to the depth of fill, and D is the kiln diameter, ft. The beam length used, L_m, is corrected for the fill ratio[1], F/D. The factor 0.55D is based on the geometrical average chord length from a point to any other point on a circle of diameter D. This factor considers the beamlength for an infinitely thin kiln section volume. The beam length for a kiln volume of kiln length equal to the kiln diameter has a value of

0.6 and is defined by the equation

$$L_m = 0.9(4V/A)$$

where V is the volume, A is the bounding surface area, and 0.9 is a correction factor to correct for finite optical thickness.

The relative partial pressures of CO_2 and H_2O, throughout the kiln were assumed to be the same as the gas exiting the kiln. This assumption is thought to be reasonable because the water in the solid bed of the kiln is likely to be evaporated in the first few feet. For a co-current kiln, the gas composition does not change appreciably further down the kiln, only the temperature changes significantly.

The objective of the gas database is to predict the gas emissivity at a specific gas partial pressure, P, for CO_2 and H_2O and specific gas beamlength, L_m, within a range of gas temperatures (500°R to 4000°R) and PL_m (0.2 to 5 ftAtm). The emissivity of H_2O and CO_2 are calculated separately and then, using Hottel's equations (discussed above), the emissivity and absorptivity of the gas mixture are calculated.

The first step is to regress Hottel's gas emissivity data for H_2O to determine gas emissivity as function of PL_m at 500°R increments of temperatures between 500°R and 4000°R. This results in 8 sets of constants, one set for each temperature, which can be used to estimate the gas emissivity at a specific PL_m. These 8 values (at a specific PL_m) are then regressed to determine gas emissivity as a function of gas temperature.

A similar procedure is used to determine the gas emissivity of CO_2 as a function of temperature at a specific PL_m. At this point, Hottel's equations are then used to calculate first the gas mixture emissivity and secondly the gas mixture absorptivity as a function of the surface radiating temperature. This procedure is outlined in further detail below:

(1) In a separate program listed in Appendix G, the emissivity data from Hottel were tabulated for each temperature in the temperature range of interest (500°R to 4000°R) for partial pressure times beam lengths (pL_m) of 0.2 to 5 (ft-atm.).

(2) These data were then regressed by a least squares method to give emissivity as a function of pL_m for the different temperatures tabulated (i.e. 500, 1000, ..., 4000°R). For each temperature, the regression method calculates the emissivity with a three term quadratic equation fit of the form:

$$\varepsilon_g = A+B(pL_m)+C(pL_m)^2$$

An example of this regression procedure is shown in Table 4.5-1 for 500°R. This regression procedure resulted in a matrix of constants (Table 4.5-2) which were then used in the heat transfer program to generate a set of emissivity values (Table 4.5-3) for the tabulated temperatures (500, 1000, ..., 4000°R) at a specific pL_m value calculated for the geometry of the kiln modeled.

(3) The set of emissivity values for a specific pL_m at the tabulated temperatures was then regressed a second time by the least squares method to yield a three term quadratic equation

Table 4.5-1. Least-Squared Regression Table for H2O and CO2 for Emissivity at Constant Temperature Versus P*L

T, R	Y=EMg [b]	X=P*L FT*ATM	X^2	X^3	X^4	XY	X^2Y	N	Comparison of Estimated Values vs Actual Values T = 500 R X=P*Lm	Emg calc [a]	Emg act [b]	Regression Constants
H2O												
500	0.19	0.2	0.04	0.008	0.0016	0.038	0.0076	1	0.2	0.221	0.19	a = 0.193360
	0.23	0.3	0.09	0.027	0.0081	0.069	0.0207	1	0.3	0.234	0.23	b = 0.140591
	0.25	0.4	0.16	0.064	0.0256	0.1	0.04	1	0.4	0.247	0.25	c = -0.01491
	0.29	0.6	0.36	0.216	0.1296	0.174	0.1044	1	0.6	0.272	0.29	
	0.31	0.8	0.64	0.512	0.4096	0.248	0.1984	1	0.8	0.296	0.31	A = -0.01491
	0.33	1	1	1	1	0.33	0.33	1	1	0.319	0.33	B = 0.066708
	0.38	1.5	2.25	3.375	5.0625	0.57	0.855	1	1.5	0.371	0.38	C = 4.954584
	0.41	2	4	8	16	0.82	1.64	1	2	0.415	0.41	D = 0.239271
	0.46	3	9	27	81	1.38	4.14	1	3	0.481	0.46	E = -3.07878
	0.53	5	25	125	. 625	2.65	13.25	1	5	0.524	0.53	
	3.38	14.8	42.54	165.202	728.637	6.379	20.5861	10				
	Y	X	X#2	X#3	X#4	XY	X#2Y	N				
CO2												
500	0.108	0.2	0.04	0.008	0.0016	0.0216	0.00432	1	0.2	0.121	0.108	a = 0.113014
	0.12	0.3	0.09	0.027	0.0081	0.036	0.0108	1	0.3	0.124	0.12	b = 0.038437
	0.13	0.4	0.16	0.064	0.0256	0.052	0.0208	1	0.4	0.128	0.13	c = -0.00432
	0.14	0.6	0.36	0.216	0.1296	0.084	0.0504	1	0.6	0.135	0.14	
	0.15	0.8	0.64	0.512	0.4096	0.12	0.096	1	0.8	0.141	0.15	A = -0.00432
	0.152	1	1	1	1	0.152	0.152	1	1	0.147	0.152	B = 0.017004
	0.165	1.5	2.25	3.375	5.0625	0.2475	0.37125	1	1.5	0.161	0.165	C = 4.954584
	0.17	2	4	8	16	0.34	0.68	1	2	0.173	0.17	D = 0.126333
	0.18	3	9	27	81	0.54	1.62	1	3	0.189	0.18	E = -3.07878
	0.2	5	25	125	625	1	5	1	5	0.197	0.2	
	1.515	14.8	42.54	165.202	728.637	2.5931	8.00557	10				
	Y	X	X#2	X#3	X#4	XY	X#2Y	N				

a EMg = a + b*(P*L) + c*(P*L)*(P*L)
b Emissivity Data from Hottel and Sarofrim

Table 4.5-2. Least-Squared Reduction Constants for H2O and CO2 Emissivity at Constant Temperature vs P*L

Degrees Rankine	Emissivity Regression Constants[a] a	b	c
H2O Constants			
500	0.193360	0.140591	-0.01491
750	0.150427	0.146890	-0.01723
1000	0.136173	0.144277	-0.01638
1500	0.109983	0.139809	-0.01478
2000	0.082221	0.129614	-0.01381
2500	0.057915	0.116838	-0.01258
3000	0.044245	0.099847	-0.01027
3500	0.034452	0.083375	-0.00838
4000	0.024206	0.074278	-0.00771
CO2 Constants			
500	0.113014	0.038437	-0.00432
1000	0.085994	0.045063	-0.00570
1500	0.097287	0.047224	-0.00544
2000	0.094390	0.059833	-0.00743
2500	0.077821	0.060663	-0.00717
3000	0.061488	0.056025	-0.00637
3500	0.049351	0.045795	-0.00480
4000	0.039099	0.036061	-0.00344
4500	0.072831	0.140905	-0.04336

a EMg = a + b*(P*L) + c*(P*L)*(P*L)

shown in Table 4.5-3 which now calculated the emissivity for a specific pL_m as a function of temperature:

$$\varepsilon_g = a+b(T)+c(T)^2$$

Table 4.5-4 shows a comparison of emissivity values calculated by this method with Hottel's data.

(4) The correction factor required to compensate for the overlap of the CO_2 and H_2O radiation spectra was calculated as a function of pL_m for an average temperature of 1000°K and mole fraction ratio of CO_2 to H_2O = 0.35. Typically the CO_2 partial pressure is about 0.12 atmospheres as determined from the overall kiln heat and mass balance gas composition. The temperature and gas composition were chosen as values characteristic of typical operation for this kiln. The use of a single average temperature and mole fraction ratio for calculating the correction factor C_{so} is considered reasonable in light of the small emissivity correction (1% to 7%) that is involved. Again, a least squares regression method was used to calculate a function for the correction factor, C_{so}, of the form:

$$C_{so} = A+B(pL_m)+C(pL_m)^2$$

The table used to generate the equation for the correction factor is shown in Table 4.5-5 and listed in Appendix G. The program could be used to generate new values for the constants, A, B, and C for different average temperatures and CO_2/H_2O ratios. The CO_2/H_2O ratios are calculated based on the

Table 4.5-3. Least-Squared Reduction Table for Emissivity at Constant P*L vs Temperature

Y=EMg (Lm = 5) [a]	X=T, R	Y=EMg	X=T	X^2	X^3	X^4	XY	X^2Y	N
H2O									
0.524	500	0.524	500	250000	1.3E+08	6.2E+10	261.7587	130879.3	1
0.454	750	0.454	750	562500	4.2E+08	3.2E+11	340.4708	255353.1	1
0.448	1000	0.448	1000	1000000	1.0E+09	1.0E+12	447.9210	447921.0	1
0.439	1500	0.439	1500	2250000	3.4E+09	5.1E+12	659.0545	988581.8	1
0.385	2000	0.385	2000	4000000	8.0E+09	1.6E+13	770.0440	1540088.	1
0.327	2500	0.327	2500	6250000	1.6E+10	3.9E+13	818.7107	2046776.	1
0.287	3000	0.287	3000	9000000	2.7E+10	8.1E+13	859.6425	2578927.	1
0.242	3500	0.242	3500	12250000	4.3E+10	1.5E+14	846.4041	2962414.	1
0.203	4000	0.203	4000	16000000	6.4E+10	2.6E+14	810.4573	3241829.	1
		3.308	18750	51562500	1.6E+11	5.5E+14	5814.464	14192772	9
CO2									
0.197	500	0.197	500	250000	1.3E+08	6.2E+10	98.52694	49263.47	1
0.169	1000	0.169	1000	1000000	1.0E+09	1.0E+12	168.5753	168575.3	1
0.197	1500	0.197	1500	2250000	3.4E+09	5.1E+12	295.7766	443664.9	1
0.208	2000	0.208	2000	4000000	8.0E+09	1.6E+13	415.1764	830352.9	1
		0.770	5000	7500000	1.3E+10	2.2E+13	978.0554	1491856.	4
0.202	2500	0.202	2500	6250000	1.6E+10	3.9E+13	504.6909	1261727.	1
0.182	3000	0.182	3000	9000000	2.7E+10	8.1E+13	546.9544	1640863.	1
0.158	3500	0.158	3500	12250000	4.3E+10	1.5E+14	553.9544	1938840.	1
0.133	4000	0.133	4000	16000000	6.4E+10	2.6E+14	532.7577	2131031.	1
		0.676	13000	43500000	1.5E+11	5.3E+14	2138.357	6972462.	4

Comparison of Estimated Values vs Actual Values:

H2O

X=T	Emg calc [b]	Emg act [a]	Regression Constants
500	0.502	0.524	a = 0.5414497507
750	0.481	0.454	b = -0.000078845
1000	0.461	0.448	c = -0.000000001
1500	0.419	0.439	
2000	0.377	0.385	A = -0.000000001
2500	0.334	0.327	B = -0.000086220
3000	0.290	0.287	C = 4400
3500	0.245	0.242	D = 0.5472118973
4000	0.199	0.203	E = -3437500

CO2

X=T	Emg calc [b]	Emg act [a]	Regression Constants	
500	0.193	0.197	0< T <2500 R	2500< T <4000 R
1000	0.180	0.169		
1500	0.186	0.197	A = 0.000000036	A = -0.000000005
2000	0.211	0.208	B = 0.000012042	B = -0.000046021
2500	0.202	0.202	C = 2500	C = 6500
3000	0.182	0.182	D = 0.177547454	D = 0.318483269
3500	0.159	0.158	E = -1250000	E = -10250000
4000	0.133	0.133		
			a = 0.226150349	a = 0.2618517862
			b = -0.00008516	b = -0.000010108
			c = 0.000000036	c = -0.000000005

a Values from first regression; EMg = a + b*(PL) + c*(PL)*(PL)

b EMg = a + b*(T) + c*(T)*(T)

Table 4.5-4. Actual vs Estimated Emissivity

P*L	ACTUAL	ESTIMATE	DELATA	ACTUAL	ESTIMATE	DELTA	ACTUAL	ESTIMATE	DELATA	ACTUAL	ESTIMATE	DELATA	ACTUAL	ESTIMATE	DELATA	ACTUAL	ESTIMATE	DELTA	ACTUAL	ESTIMATE	DELATA	ACTUAL	ESTIMATE	DELATA
FT*ATM	TEMPERATURE = 500			TEMPERATURE = 750			TEMPERATURE = 1000			TEMPERATURE = 1500			TEMPERATURE = 2500			TEMPERATURE = 3000			TEMPERATURE = 3500			TEMPERATURE = 4000		
H2O																								
0.2	0.19	0.210	-10.5%	0.15	0.189	-26.2%	0.13	0.170	-30.6%	0.115	0.135	-17.4%	0.065	0.081	-25.1%	0.05	0.063	-25.0%	0.039	0.049	-25.8%	0.03	0.041	-36.4%
0.3	0.23	0.224	2.7%	0.185	0.203	-9.7%	0.175	0.183	-4.7%	0.14	0.148	-5.6%	0.088	0.092	-5.0%	0.07	0.072	-3.4%	0.053	0.057	-8.3%	0.042	0.048	-13.2%
0.4	0.25	0.237	5.1%	0.205	0.216	-5.5%	0.19	0.196	-3.4%	0.165	0.161	2.7%	0.105	0.103	1.6%	0.083	0.082	1.2%	0.067	0.066	2.2%	0.053	0.054	-1.9%
0.6	0.29	0.263	9.3%	0.25	0.242	3.2%	0.235	0.222	5.6%	0.2	0.185	7.6%	0.13	0.124	4.4%	0.108	0.101	6.9%	0.088	0.081	7.6%	0.07	0.066	5.0%
0.8	0.31	0.288	7.2%	0.275	0.266	3.2%	0.26	0.246	5.4%	0.23	0.208	9.6%	0.155	0.144	7.0%	0.125	0.118	5.4%	0.105	0.096	8.2%	0.085	0.078	7.8%
1	0.33	0.311	5.8%	0.3	0.289	3.5%	0.28	0.269	4.0%	0.25	0.230	8.0%	0.17	0.163	4.0%	0.14	0.135	3.5%	0.115	0.111	3.8%	0.098	0.090	8.4%
1.5	0.38	0.363	4.4%	0.34	0.342	-0.4%	0.325	0.320	1.5%	0.295	0.280	5.2%	0.21	0.206	1.8%	0.177	0.173	2.0%	0.15	0.143	4.5%	0.12	0.116	3.6%
2	0.41	0.408	0.6%	0.36	0.386	-7.1%	0.35	0.364	-4.0%	0.32	0.322	-0.6%	0.23	0.243	-5.7%	0.2	0.206	-3.2%	0.16	0.171	-7.1%	0.14	0.138	1.3%
3	0.46	0.472	-2.5%	0.42	0.450	-7.1%	0.4	0.428	-6.9%	0.38	0.384	-1.1%	0.29	0.298	-2.8%	0.24	0.256	-6.6%	0.2	0.214	-7.0%	0.17	0.173	-1.5%
5	0.53	0.502	5.4%	0.46	0.481	-4.6%	0.455	0.461	-1.3%	0.445	0.419	5.8%	0.33	0.334	-1.2%	0.29	0.290	0.1%	0.245	0.245	0.0%	0.205	0.199	2.8%
	AVERAGE % ERROR		5.3%			7.1%			6.8%			6.4%			5.9%			5.7%			7.4%			8.2%
CO2																								
0.2	0.108	0.118	-9.3%	0.085	0.102	-20.3%	0.095	0.099	-4.3%	0.095	0.109	-14.3%	0.08	0.090	-12.0%	0.064	0.073	-13.5%	0.052	0.058	-11.8%	0.04	0.046	-15.6%
0.3	0.12	0.122	-1.4%	0.095	0.106	-11.8%	0.108	0.104	4.0%	0.108	0.114	-5.6%	0.09	0.095	-5.9%	0.074	0.078	-5.1%	0.06	0.063	-4.3%	0.048	0.050	-3.4%
0.4	0.13	0.125	3.6%	0.105	0.110	-4.9%	0.12	0.108	9.8%	0.12	0.119	0.4%	0.1	0.101	-0.9%	0.083	0.083	0.1%	0.067	0.067	0.2%	0.053	0.053	0.0%
0.6	0.14	0.132	5.5%	0.115	0.118	-2.4%	0.127	0.117	7.9%	0.13	0.130	0.1%	0.119	0.112	6.1%	0.096	0.093	3.5%	0.079	0.075	4.7%	0.062	0.059	4.1%
0.8	0.15	0.139	7.4%	0.125	0.125	0.1%	0.135	0.125	7.3%	0.145	0.140	3.7%	0.128	0.122	4.8%	0.108	0.102	5.6%	0.087	0.083	4.4%	0.069	0.066	4.9%
1	0.152	0.145	4.6%	0.132	0.132	0.3%	0.145	0.133	8.4%	0.155	0.149	4.0%	0.138	0.131	4.7%	0.119	0.111	7.0%	0.094	0.091	3.4%	0.076	0.072	5.8%
1.5	0.165	0.159	3.6%	0.142	0.147	-3.2%	0.16	0.150	6.2%	0.17	0.169	0.4%	0.158	0.153	3.2%	0.133	0.130	1.9%	0.11	0.108	1.9%	0.088	0.085	3.2%
2	0.17	0.171	-0.4%	0.152	0.159	-4.6%	0.17	0.164	3.4%	0.18	0.186	-3.5%	0.168	0.171	-1.6%	0.148	0.147	0.6%	0.12	0.123	-2.2%	0.097	0.097	-0.1%
3	0.18	0.187	-4.0%	0.162	0.176	-8.8%	0.18	0.183	-1.9%	0.2	0.209	-4.5%	0.185	0.196	-5.7%	0.163	0.171	-5.0%	0.138	0.145	-4.8%	0.11	0.116	-5.4%
5	0.2	0.193	3.4%	0.171	0.180	-5.2%	0.2	0.186	7.1%	0.21	0.211	-0.6%	0.205	0.202	1.4%	0.185	0.182	1.7%	0.16	0.159	0.8%	0.135	0.133	1.5%
	AVERAGE % ERROR		4.3%			6.2%			6.0%			3.7%			5.8%			5.7%			7.5%			8.2%

(ACTUAL EMISSIVITY DATA FROM HOTTEL AND SAROFRIM)

Table 4.5-5. CO2 and H2O Emissivity Overlap Correction Factor

Regression Table

								Comparison of Estimated Values vs Actual Values:				
Y=Cso [a]	X=PL	X^2	X^3	X^4	XY	X^2Y	N	X=PL	Cso calc [b]	Cso act [a]	Regression Constants	
0.016	0.10	0.01	0.00	0.00	0.00	0.00	1.00	0.10	0.02	0.02	a =	0.0122
0.030	0.25	0.06	0.02	0.00	0.01	0.00	1.00	0.75	0.05	0.05	b =	0.0660
0.052	0.75	0.56	0.42	0.32	0.04	0.03	1.00	1.00	0.06	0.06	c =	-0.0193
0.059	1.00	1.00	1.00	1.00	0.06	0.06	1.00	1.50	0.07	0.07		
0.065	1.50	2.25	3.38	5.06	0.10	0.15	1.00	2.00	0.07	0.07	A =	-0.02
0.068	2.00	4.00	8.00	16.00	0.14	0.27	1.00				B =	0.03
-------	--------	--------	--------	--------	--------	--------	--------				C =	2.05
0.290	5.60	7.89	12.81	22.38	0.34	0.51	6.00				D =	0.02
Y	X	X#2	X#3	X#4	XY	X#2Y	N				E =	-0.60

a GAS PARTIAL PRESSURE RATIO OF Pco2/(PH2O+PCO2) = .35
GAS TEMPERATURE = 1000 R
Data from Hottel and Sarofrim

b Cso = a + b*(P*Lm) + c*(PLm)*(Plm)

results from the overall heat and mass balance gas composition for the kiln. A procedure similar to that used to calculate the emissivity (i.e., by regressing data) could have been used. However it was felt that the small gain in accuracy did not justify the additional computational effort.

(5) The emissivity of the gas mixture was determined as specified by Hottel's equations by adding the separately calculated emissivity values for CO_2 and H_2O and applying the correction factor, C_{so}.

(6) The absorptivity of the gas mixture was determined as specified by Hottel's equations by adding the separately calculated absorptivity values for CO_2 and H_2O and applying the correction factor, C_{so}.

This regression method of estimating the gas emissivity has not been treated in the literature. This approach was also undertaken in part because the indirect-fired kiln model required the calculation of the emissivity of the inner shell gas which contained water but no CO_2. The literature calculations of emissivity have been made only for combustion gases, which included CO_2. The emissivities of CO_2 and H_2O could have been calculated separately also by using a gray/clear gas model. The emissivity and absorptivity of the kiln gas could then be calculated as suggested by Hottel. This would require knowledge of the weighting factors for CO_2 and H_2O. (See Section 4.5). The method for determining these factors had not been found during the model development but later was found reported in the thesis of T.R.

Johnson[55]. See Appendix G for the program listing of the gas data base.

4.6 Transmissivity of the Gas for Its Own Radiation

Introduction- The transmissivity of the gas for its own radiation is much lower than the absorption of radiation from a solid through the gas. The gas emission and absorption is characterized by two sharp peaks or bands in the infrared spectrum, while the black body or gray body radiation is continuous over the spectrum of interest. The absorption by the gas for gray or black body radiation will occur only within the bands or peaks in the gas spectrum, and therefore will result in lower values of gas absorptivity (and gas emissivity) than a black body. However the gas absorptivity for its own radiation is relatively high because the characteristic peaked radiation wavelength spectrum emitted by the gas is also the wavelength spectrum absorbed by the gas.

Previous Work -

The method as presented by Gorog[1] uses the weighting factors and absorption coefficients for the gray/clear gas model[1] to characterize the weighted average transmissivity of the gas for its own radiation, τ'_g, as shown in the following equation:

$$\tau'_g = \sum_{i=1}^{N} a_i K_i (e^{-K_i p L_m}) \Big/ \sum_{i=1}^{N} a_i K_i$$

Each weighting factor, a_i, represents the fraction of black body energy in the emitting/absorbing wavenumber region associated with the absorption coefficient K_i. The term p represents the combined partial pressures of CO_2 and H_2O, and L_m is the average beam length of the gas in the enclosure. The equation has a similar form to that used to estimate the gray/clear gas emissivity. In the emission case, the weighting factors (a_i) refer to the ratio of the energy emission in the emitting wave number region of the gas to the total black body emission, and the denominator is the total black body emission which is defined equal to 1. However in this case, the denominator of the equation represents the total gas energy emission obtained by summing of the weighting factors (a_i) times the absorption coefficients (K_i). The numerator is the total gas energy transmitted through the gas and is equal to the summation of the product of a_iK_i times the transmissivity ($e^{-K_i pL_m}$) for each K_i. The strong absorption of the gas for its own radiation is inherently treated in the Zone Method heat transfer analysis in the use of the gray/clear gas model weighting factors and absorption coefficients. However, the gas transmissivity for its own radiation is not discussed in studies which used the Resistive Network Method.

<u>Current Work</u> -

The present study does not use a gray/clear gas model to evaluate the transmissivity of the gas for its own radiation.

Rather this transmissivity (τ'_g) is determined (estimated) by a separate radiation balance (incorporated in the program) from the special case when the temperatures of the gas and all the surfaces are the same. In this situation, the heat flow from the gas to the solid surfaces can be equated to the heat flow from these surfaces to the gas so that the net gas-surface radiant heat exchange for each gas-surface pair is zero. The algebraic equations expressing this balance can be solved for the unknown transmissivity value of the gas for its own radiation when the other parameters affecting the heat balance (such as surface reflectivities, transmissivity of the gas for black body radiation, view factors, etc.) are specified.

The value of τ'_g calculated in this way can then be used in constructing heat balances for the usual cases where the solid surface temperatures do not equal the gas temperature. This approach is valid because the value of τ'_g is a function only of the gas temperature and composition and is independent of the surface temperatures.

Consider the simplified case of a single surface enclosure (kiln wall) with a participating gas (see Fig. 4.6-1). If the temperature of the wall and gas are equal, the system is at steady state, and the energy emitted from the wall and absorbed by the gas must be equal to the energy emitted by the gas and absorbed by the wall. That is

$$Q_{wg} = Q_{gw},$$

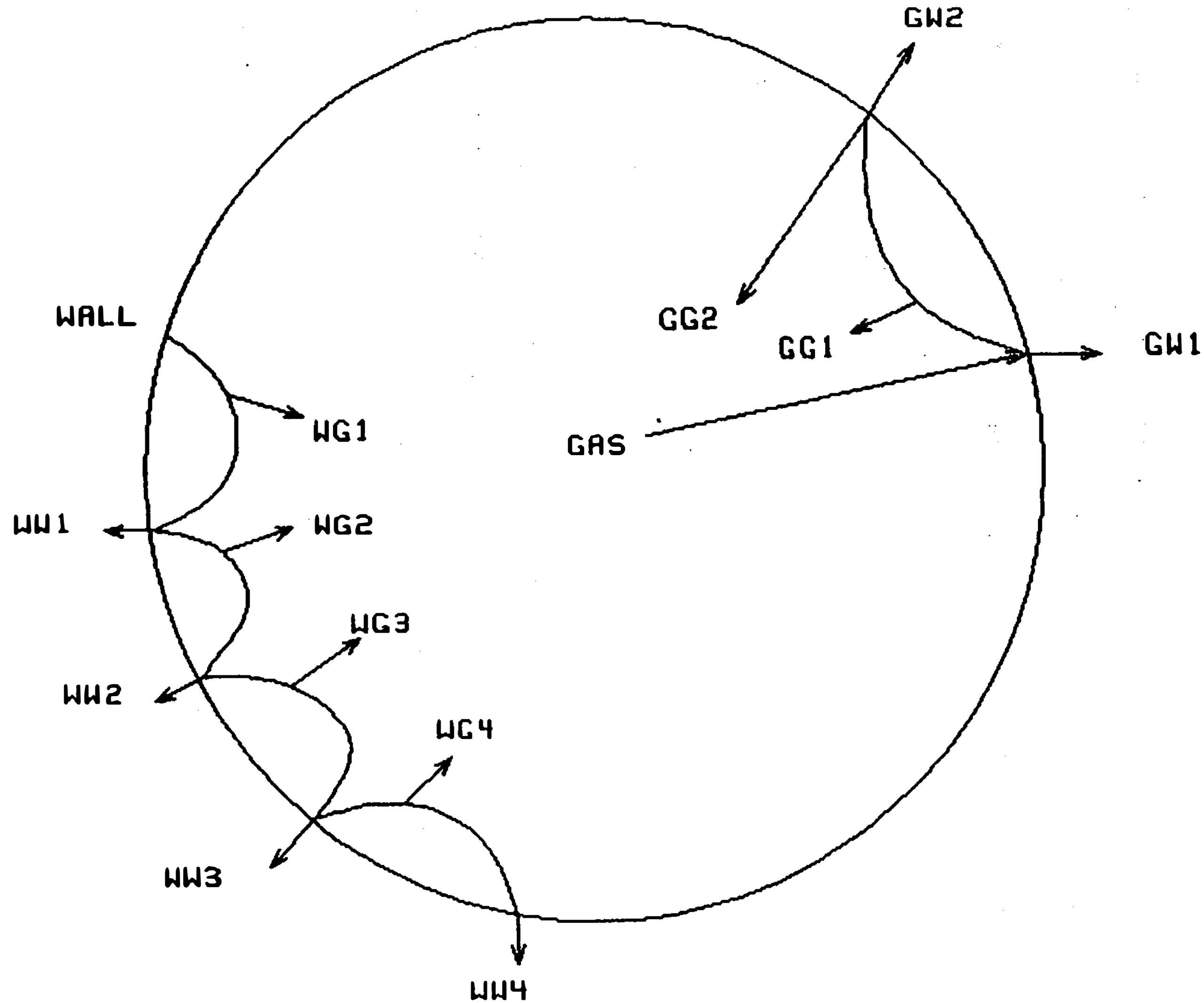


Figure 4.6-1. Radiation Drawing for Single Surface Enclosure with a Participating Gas

or from Fig. 4.6-1,

$$Q_{wg_1} + Q_{wg_2} + Q_{wg_3} = Q_{gw_1} + Q_{gw_2},$$

where Q_{wg_1}, Q_{wg_2}, and Q_{wg_3} are terms representing radiation from the wall absorbed by the gas, and Q_{gw_1} and Q_{gw_2} are terms representing radiation from the gas to the wall. The wall terms are,

$$Q_{wg} = ((1-\tau_{g1}) + \rho_w(\tau_{g1}-\tau_{g2}) + \rho_w^{2}(\tau_{g2}-\tau_{g3}))\varepsilon_w A_w \xi_w$$

and for the gas,

$$Q_{gw} = (1+\tau'_g \rho_w)\alpha_w \varepsilon_g A_g \xi_g.$$

The term ξ_w and ξ_g are the surface and gas emittance (σT^4), ρ_w is the surface reflectivity, α_w the surface absorptivity, ε_g is the gas emissivity, and τ_{g1}, τ_{g2}, and τ_{g3} are the gas transmissivities (for black body radiation) for beam lengths corresponding to the original ray, and its first and second reflections, respectively.

Noting that:

1. $\alpha_w = \varepsilon_w$ for a gray body,
2. $T_g = T_w$ so $\xi_w = \xi_g$, and finally,
3. $A_w = A_g$, and therefore, $\varepsilon_w A_w \xi_w = \alpha_w A_g \xi_g$,
4. Noting the approximation for a real gas that $\varepsilon_g = 1-\tau_{g1}$,

Equating $Q_{wg} = Q_{gw}$, and canceling equivalent terms:

$$(1-\tau_{g1}) + \rho_w(\tau_{g1}-\tau_{g2}) + \rho_w^2(\tau_{g2}-\tau_{g3}) = (1+\tau'_g\rho_w)\varepsilon_g$$
$$= \varepsilon_g + \varepsilon_g\tau'_g\rho_w$$
$$= 1-\tau_{g1} + \rho_w\varepsilon_g\tau'_g$$

Solving the expression for τ'_g:

$$\tau'_g = ((\tau_{g1}-\tau_{g2}) + \rho_w(\tau_{g2}-\tau_{g3}))/\varepsilon_g \qquad \text{Eq. 4.6-1}$$

It may be seen that Eq. 4.6-1 includes a small term involving the solid wall surface reflectivity, ρ_w. With a higher ρ_w, the reflections of the original radiation emitted by the wall would be stronger and permit more wall radiation to be absorbed by the gas. Because the radiation from the gas to the wall must equal the radiation from the wall to the gas where both are at the same temperature, the mathematical result using the Reflection Method is that τ'_g must increase to compensate for the larger fraction of reflected gas radiation which strikes the wall. (Incorporating a larger number of reflection terms in this balance does not cancel the presence of the ρ term.)

The heat balance equations for Q_{sg}, Q_{wg}, and Q_{fg} were copied and edited in the program for calculating τ'_g so that the temperature of the solid, wall, and flame used in these equations was that of the gas. (See Fig. 4.6-2). The solid-to-gas equations represent the net heat absorbed by the gas from radiation originating from the solids. The gas-to-solids equations (Q_{gs}, Q_{gw}, and Q_{gf}) represent the net heat absorbed by the solids from the radiation originating

```
sg     1 -(1-TRgg1)*EMs*As                                   -0.0835
       2 -(TRgg1-TRgg2)*Fsw*pw*EMs*As                        -0.0026
       3 -(TRgg2-TRgg3)*Fww*Fsw*pw*pw*EMs*As                 -0.0002
       4 -(TRgg2-TRgg3)*Fws*Fsw*ps*pw*EMs*As                 -0.0001
                                                             -0.0864

wg     1 -(1-TRgg1)*EMw*Aw                                   -0.3175
       2 -(TRgg1-TRgg2)*Fww*pw*EMw*Aw                        -0.0077
       3 -(TRgg2-TRgg3)*Fww*Fww*pw*pw*EMw*Aw                 -0.0007
       4 -(TRgg2-TRgg3)*Fws*Fsw*ps*pw*EMw*Aw                 -0.0003
       5 -(TRgg2-TRgg3)*Fws*Fww*ps*pw*EMw*Aw                 -0.0002
       6 -(TRgg1-TRgg2)*Fws*ps*EMw*Aw                        -0.0026
                                                             -0.3290

fg     1 -(1-TRgg1)*EMf*Af                                   -0.1546
       2 -(TRgg1-TRgg2)*ps*Ffs*EMf*Af                        -0.0016
       3 -(TRgg2-TRgg3)*ps*pw*Ffs*Fsw*EMf*Af                 -0.0002
       4 -(TRgg1-TRgg2)*pw*Ffw*EMf*Af                        -0.0056
       5 -(TRgg2-TRgg3)*pw*ps*Ffw*Fws*EMf*Af                 -0.0002
       6 -(TRgg2-TRgg3)*pw*pw*Ffw*Fww*EMf*Af                 -0.0005
                                                             -0.1627

TRg11 = (-(Tfg+Twg+Tsg)-EMg*(Af+ABw*Aw+ABs*As))
        /(EMg*(pw*Aw*(Fwf+ABw*Fww+ABs*Fws)+ps*As*(Fsf+ABw*Fsw)))
      =                              0.2599
TRgs11 = (-tsg-ABs*EMg*As)/(ABs*pw*Fws*EMg*Aw)
      =                              0.2601

TRgw11 = (-twg-ABw*EMg*Aw)/((pw*Fww*Aw+ps*Fsw*As)*ABw*EMg)
      =                              0.2599

TRgf11 = (-tfg-Af*EMg)/((pw*Fwf*Aw+ps*Fsf*As)*EMg)
      =                              0.2599
```

Figure 4.6-2. Calculation of Gas Transmissivity for Its Own Radiation from the gas. The value of the transmissivity of the gas for its own radiation, τ'_g is the only parameter in this balance which has not been specified in this copied set of equations. These equations are solved numerically for this value, τ'_g. The value of τ'_g obtained in this manner is slightly higher than the value derived by the gray/clear gas method, and accounts for the radiation reflected by the enclosure surface.

4.7 Flame Emissivity

Previous Work -

Luminous radiation from flames occurs mainly as a result of the radiation from suspended solid particles. These particles, usually carbon, heavy hydrocarbon compounds, or ash (as in coal flames) emit significant amounts of radiation through a continuous spectrum extending into the visible range. The particles of carbon or heavy hydrocarbon compounds are termed soot, and result from thermal decomposition of fuel under oxygen deficient conditions.

The prediction of flame radiation characteristics is a complex problem on which much research work is currently being done[51]. The emissivity of a luminous flame could be predicted satisfactorily provided one knew:

1. the distribution of soot within the flame, and
2. the optical properties of the soot in the flame.

However these properties have been measured only for a few particular flames different from that in the kiln used to test this model. These quantities have not been calculated from theoretical considerations, but have been estimated from experimental measurements. Absorption coefficients appear to depend strongly on the chemical composition of the soot, but there is no way of knowing what these values will be at any point in the flame (Johnson)[35]. The general theoretical prediction of flame characteristics is difficult because it involves the simultaneous characterization of turbulent fluid flow, the kinetics of the fuel burning reaction and the kinetics of the burnout of soot formed in flames, taking into account the heat and mass transfer problems involved. Each of these phenomena is affected by particular kiln operating conditions such as burner configuration, kiln configuration, firing rate, fuel type, and excess air usage.

Characterization of a flame has therefore been limited to particular flames for specific operating conditions where experimental measurements have been made. Only a few detailed experimental studies of industrial type flames have been found in the literature (Jenkins[38], Johnson[35], Weber[40], Falliot[41]). This is in part due to the inherent complexity of such studies.

In the absence of experimental data, the flame is commonly modeled in the literature (Brimacombe[3]) as a gray or black body. With the use of the gray flame model, heat transfer estimates sufficiently accurate for most practical purposes have been made. The emissivity of a gray flame is dependent on the type of fuel combusted (related to the average molecular weight of the fuel) and, to some extent on the firing rate, burner configuration, flame diameter, and amount of air in and around the burner. Gas flames have a low emissivity in the range of 0.4 to 0.6. Coal flames have a high emissivity in the range of 0.9 to 1.0, in part due to the ash present in coal[3].

<u>Current Work</u> -

An alternative to the gray body treatment to determine the flame emissivity is to estimate the optical properties and distribution of soot in the flame based on empirical data from other flames. However such data are scarce and of questionable applicability to the modeled flame. Due to the high emissivity of oil and coal flames (.8 to 1.0), the error introduced by treating the flame as a gray body is relatively small (Brimacombe)[3]. Therefore in view of the absence of reliable experimental data, and the relatively small error introduced, the flame is treated in the present model as (a modified black body which is equivalent to) a gray body with an emissivity of 0.8 which is in the range of fuel oil flames of 0.8 to 1.0 suggested by Brimacombe[3] and Thring[34].

5.0 CONVECTIVE AND CONDUCTIVE HEAT TRANSFER

<u>Previous Work</u> -

Convection and conduction usually account for 10% to 30% of the heat transferred in a rotary kiln (Brimacombe, Johnson, Jenkins, Weber[40], Folliot[41]). Values of heat transfer coefficients are reported by several authors in the literature Brimacombe, Watkinson[42], Tscheng and Watkinson[47], and Kreith[43] among others.

<u>Current Work</u> -

Values of heat transfer coefficients (HTC) cited in the program were those reported by Brimacombe and Watkinson[42]. The coefficient values are variables which are input in the program.

An alternative would have been to use equations cited by the above authors to estimate the HTC values. However these equations are approximate, and sufficient data to apply them are not available in all cases.

The convective heat transferred from the gas to the solid bed and wall accounts for 5% to 10% of the heat transferred to the wall and bed. The value for convective HTC from the <u>gas to the wall</u> is based on Eq. 5.0-1 (Tscheng and Watkinson)[47].

$$h_{cvgw} = 0.036(K_g/D)Re^{0.8}\,P_r^{0.33}\,(D/L)^{0.55} \qquad \text{Eq 5.0-1}$$

where

K_g = gas thermal conductivity W/m K

Re = Reynolds number = $\rho VD/\mu$

where ρ = gas density

V = gas velocity

D = kiln diameter, m

μ = viscosity, kg/m s

P_r = Prandl number = $C_p\mu/K$

where, C_p = heat capacity of the gas

K = thermal conductivity of the gas, W/m

D = kiln diameter, m

L = kiln length, m

The value obtained from this HTC varied from 3 to 5 BTU/ft^2 F in the results published by Tscheng and Watkinson[47].

The value for convective HTC from the gas to the solid bed is the least well known of all the heat transfer coefficients. No verified equation[3] has been found in the literature to calculate the value. The equation cited by Brimacombe is

$$h_{cvgs} = 0.4\ G'_g{}^{0.62}$$

where G'_g = gas mass flux Kg/m^{2}hr

So again, the values reported by Brimacombe[3] of 8 to 16 BTU/ft^{2}F were used. Variations in the convective heat transfer coefficient will not significantly affect the overall heat transfer due to the small contribution from heat transferred by convection (5 to 10%).

The HTC between the wall and solid bed considers the heat transferred by conduction inside the kiln from the wall section covered by the solid bed to the solid bed. The following equation is cited by Tscheng and Watkinson[47] for conductive heat transfer:

$$h_{cdws} = 11.6\ K_s/D\gamma_L\ (\omega R_I{}^2\gamma_L/30\ k_s)^{0.3}$$

where,

K_s = solid thermal conductivity W/m K

k_s = solids thermal diffusivity, m^2/s

γ_L = solid bed half angle

D = kiln diameter, m

R = inner kiln radius, m

ω = rev/s

The value using this equation was not calculated for soil and again Brimacombe's estimate was used. The reported range of the value for limestone is 8 to 16 BTU/ft^{2}F.

The suggested ranges from these literature references for the HTC values are considered acceptable because of the small effect convection and conduction heat transfer have in a rotary kiln. The program allows for the input of more reliable HTC values when they become available.

5.1 <u>Shell Heat Loss</u>

Shell heat loss and conduction of heat through the wall is accounted for in the model. The rate at which heat is conducted through the wall is equal to the rate at which heat is lost from the outer shell by convection and radiation. (See Fig. 5.1-1). The thermal conductivity values for the refractory materials used in the kiln modeled are a variables input to the program and are used to calculate the rate of heat conduction through the wall of the kiln by the following equation:

$$q_{cond} = h_{cd}A_3(T_w - T_{sh})$$

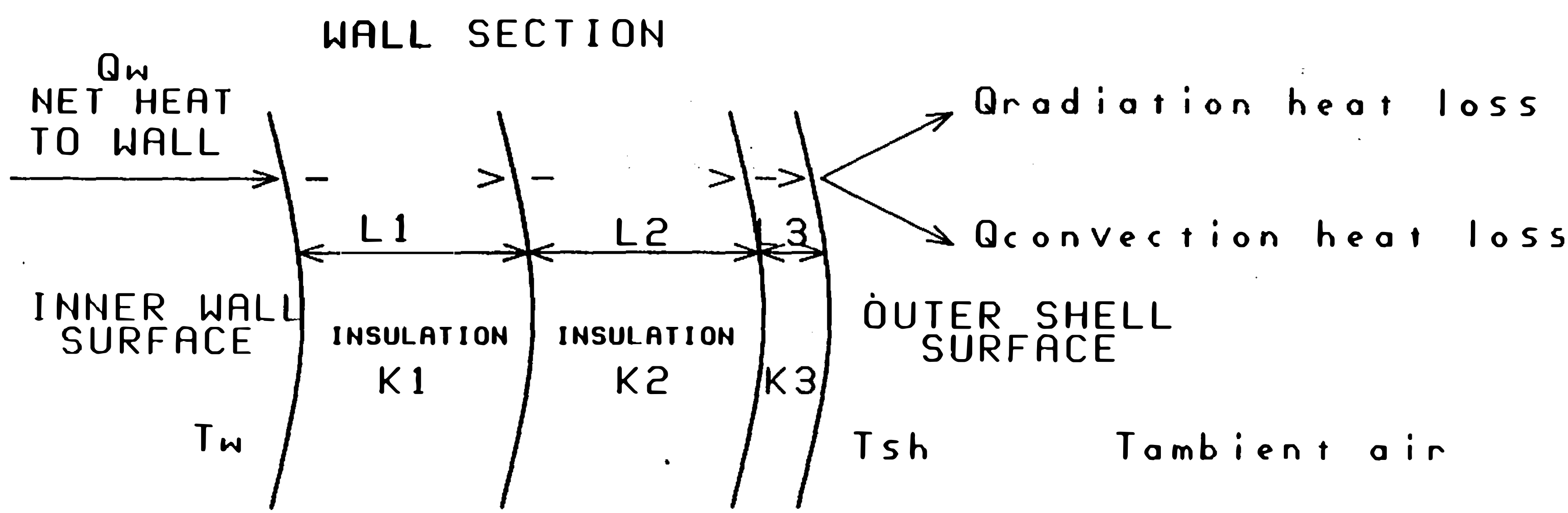


Figure 5.1-1. Shell Heat Loss

where $h_{cd} = (1/2\pi r_3)/((r_2-r_1)/(\pi K_1(r_1+r_2))+(r_3-r_2)/(\pi K_2(r_2+r_3)))$

where,

h_{cd} = conductive heat transfer coefficient, W/m^2K

A_3 = area of second layer of refractory, m^2

T_w = temperature of inner wall surface, K

T_{sh} = temperature of outer shell surface, K

r_1 = inner kiln radius, m

r_2 = kiln radius for first layer of refractory, m

r_3 = kiln radius for second layer of refractory, m

r_4 = kiln radius for outer shell thickness, m

K_i = thermal conductivity of refractory layer or shell, $W\ m/m^2K$

The value for the shell convection coefficient was taken from the range suggested by Brimacombe[3] of 3 to 5 BTU/ft^2. The equation by Brimacombe is:

$$h_{cvsh} = (K_a\ P_r^{0.3}/D)(C)(Re)^N$$

where C = 0.193 for Re values of 4,000 to 40,000, and

N = 0.618

D = outer kiln diameter, m

K_a = thermal conductivity of air W/m K

P_r = Prandl number

Re = Reynolds number

This equation is similar to the equation cited in Perry 5th edition[46] for convective heat transfer in tube bundles:

$$hD/k = a(Re)^{.6}(Pr)^{0.33}$$

where the constant a is determined by the tube bundle configuration and the amount of leakage air normal to the tube bundle.

The value for the emissivity of the outer shell was also taken from Brimacombe, and was verified using the temperature dependent equation cited by Jenkins[38]. The rate of heat loss from the shell is dependent on the outer shell temperature which in turn is related to the heat losses from the kiln interior by convection, radiation, and conduction. The determination of the outer wall temperature becomes a trial and error procedure in the program. The shell temperature could also be determined directly by the solution of a fourth order equation (if the inner wall temperature and K-values are specified). This shell heat balance is represented by Eqn. 5.1-1:

$$q_{cond} = q_{conv} + q_{rad} \qquad \text{Eq. 5.1-1}$$

substituting,

$$h_{cd}(T_w - T_{sh}) = h_{cvsh}(T_{sh} - T_a) + h_{rad}(T_{sh} - T_{amb})$$

$$h_{rad} = \sigma\ \varepsilon_{sh}\ (T_{sh}^4 - T_a^4)/(T_{sh} - T_a)$$

where, h_{cd} is the conductive HTC for the wall, h_{cvsh} is the convective HTC for the outer shell, h_{rad} is the linearized radiative HTC for the outer shell, and

T_{sh} = shell temperature, K

T_a = ambient air temperature, K

T_w = inner wall surface temperature, K

σ = Boltzmann constant, $W/m^2\ K^4$

ε_{sh} = shell emissivity

Solving for the shell temperature using Eq. 5.1-1,

$$T_{sh}=(h_{cd}A_3T_w+A_{sh}h_{cvsh}T_a+A_{sh}h_{rad}T_a)/(h_{cd}A_3+A_{sh}h_{cvsh}+A_{sh}h_{rad}))$$

Note that h_{rad} is a function of T_{sh}, and a trial and error solution of T_{sh} is required. Beginning with an initial estimated shell temperature, the program predicts a new value for the temperature of the shell which is closer to the correct value. The new temperature is then used in the program to predict a still closer approximation to the correct value. This process is repeated until the value converges to the final correct temperature. This is a simple and rapidly converging iteration. Usually a satisfactory temperature is found after only a few iterations.

6.0 DEVELOPMENT OF A COMPUTER PROGRAM FOR THE DIRECT-FIRED KILN MODEL

Current Work -

In the forgoing chapters, the main elements of a theoretical model for heat transfer in a direct-fired kiln are discussed, including a number of modifications and improvements to the basic Reflection Method as presented by Gorog[1]. In this chapter it is indicated how all of these elements are combined in an overall heat transfer model for the operation of a direct-fired kiln. A computer program was written in the LOTUS 1-2-3 worksheet language for carrying out the model calculations on a PC computer. The program listing is included in Appendix E.

The program calculates the heat transfer in the kiln for any selected set of temperatures in each section of the kiln. At steady state, the heat entering and leaving each section must balance. Radiant heat transfer among the kiln wall, hot gases, and the solid bed is the predominant mode of heat transfer, but the program also takes into account convective and conductive heat transfer within the kiln and out through the kiln wall. Heat generation by combustion of the fuel in the flame region is also accounted for. From the direction of imbalance calculated by the program on the basis of the initial set of temperatures selected by the user, the direction of adjustment of temperatures is indicated for the next set of trial temperatures. This process is repeated (usually requiring a few dozen trial iterations) until the final temperature profile for a kiln section produces a satisfactory overall heat balance. (If this program were to be used repeatedly, then the iterative process could be simplified by the use of circular reference equations for the temperature inputs in the spreadsheet. A circular reference in an equation in LOTUS 1-2-3 is noted on the bottom of the screen with a high-lighted message, CIRC, and denotes that an equation, A, which references a second equation B, is referenced in equation B. For example,

A = +B, and

B = +A+(Limit-Value)*factor,

where A is the input and B predicts the next value of A based on the difference between a desired limit and a resulting value (which is a function of the input A) times a scaling factor. This allowance of circular references in LOTUS 1-2-3 is very useful for trial and error solutions. A circular reference is allowed only in the manual calculation mode. This circular calculation procedure would automatically estimate the new trial temperatures by (manually) recalculating the worksheet until the final temperatures are obtained within a section. Different sets of circular equations would be required for the flame region and the downstream gas region.)

The program is set-up primarily to provide equations and calculational procedures to determine all of the heat transfer phenomena which take place within a single kiln section. This involves specifying parameters such as kiln geometry, feed rates, initial temperatures, fuel firing rates, etc.. It also involves tracking the enthalpy of the gas and solid bed from one kiln section to the next. Tracking these enthalpies and corresponding temperatures is a large part of the effort of using the program.

The intent of the LOTUS 1-2-3 program as written was not to develop the most efficient computer program for carrying out the calculations and iterations involved, but rather to demonstrate how a number of modifications and improving features could be incorporated in a computer program to model a rotary kiln. The intent of this chapter is to describe the calculational procedure and method involved. The program was written using the LOTUS 1-2-3 language because it is a good language allowing the user to see all of the interrelationships involved in the model. This kiln heat transfer model is the first which has been reported on a PC computer.

A faster language such as Fortran or even BASIC would be better suited for repeated use of the program to calculate the temperature profile without user assistance. Several hours may be required to compute the temperature profile in a kiln using the LOTUS 1-2-3 program as developed, where as in Fortran it is estimated that the same task could be completed in several minutes. The program development work done in LOTUS 1-2-3 could be used to write and structure a Fortran program using the flow diagram shown in Fig. 6.0-1.

6.1 Radiation Balance

The Reflection Method as originally developed by Succec[34] is basically a set of simple algebraic equations which represent

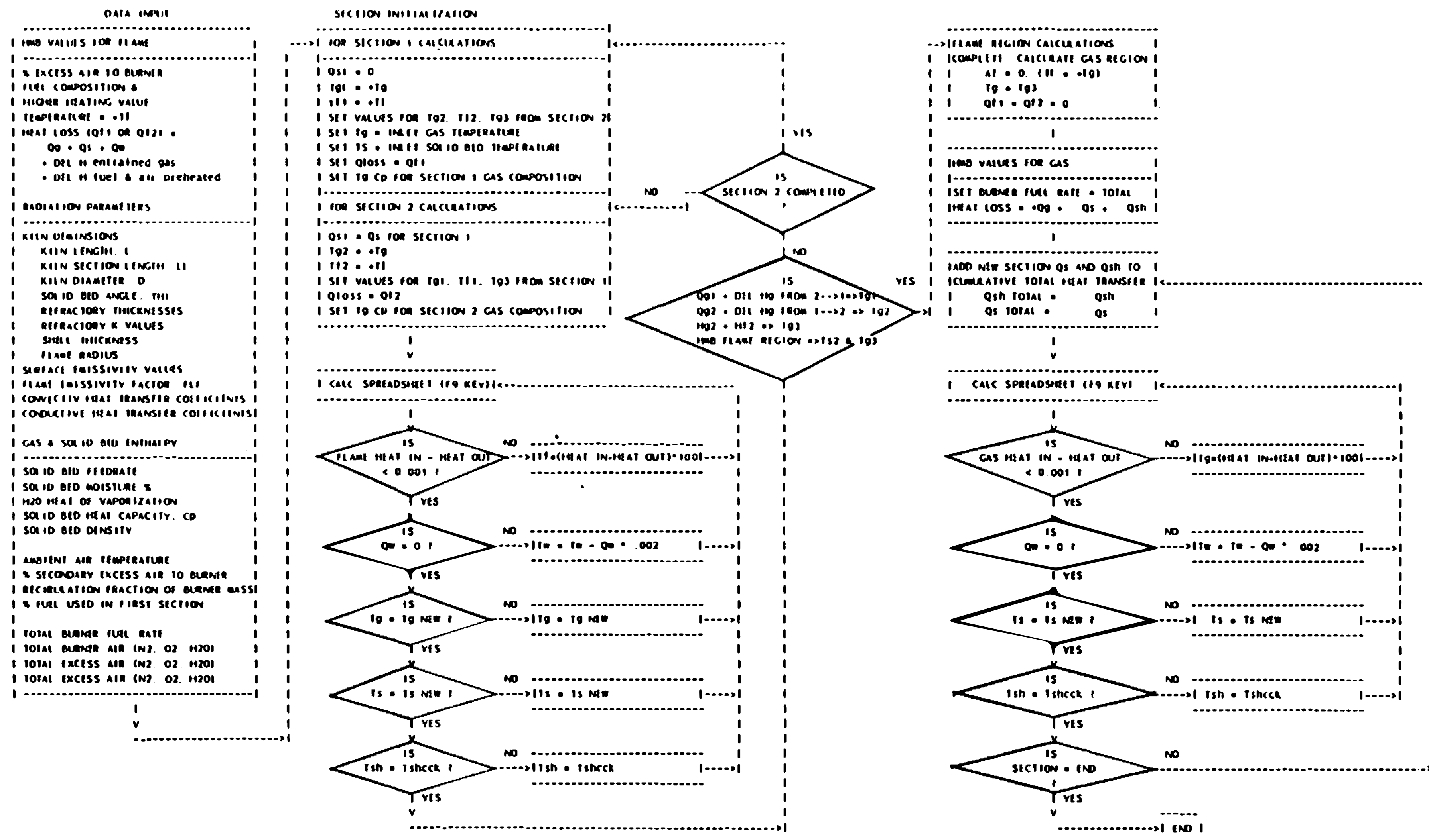


Figure 6.0-1. Computer Model Calculational Flow Diagram

the various emissions, absorptions, and reflections involved in calculating the radiation balance using the surface and gas properties and geometrical factors (view factors) required to model the kiln. (See Table 4.2-6 for list of equations in the radiation balance). The work by Gorog[1] outlines the general application of the method to a rotary kiln in which gas radiation without a flame is the principal source of heat. Gorog treated the gas as a gray/clear gas and the wall and solid bed as gray bodies. This treatment was modified in the present model to include,

(1) the effect of the flame as a radiating and absorbing body,
(2) the effect the re-entrainment of gases in the flame region,
(3) the effect of conductive and convective heat transfer, and
(4) the effect of using gas emissivity based on experimental data.

These modifications provide a more complete model of heat transfer in a direct-fired rotary kiln.

For a given set of kiln operating conditions, the modified radiation balance, using the Reflection Method, will determine the temperature profile of the gas and surfaces within the enclosure. The selection of the set of gas and surface temperatures which allows the radiation balance to be satisfied depends on the overall heat balance, including the addition of combustion heat and heat transfers by convection and conduction (Eq. 6.1-1) and any further constraints, such as steady state operation, imposed on the system by the inner kiln balance (Eq. 6.1-2)

Overall Balance

$$H_{air} + Q_{comb} = H_{gas} + H_{solids} + Q_{shell\ loss} \qquad \text{(Eq. 6.1-1)}$$

Inner Balance

$$Q_{flame} = Q_{gas} + Q_{solids} + Q_{wall} \qquad \text{(Eq. 6.1-2)}$$

where H is the enthalpy and Q is the heat gained or lost. Also the temperature distribution of the surfaces in the enclosure is such that at steady state the rate of energy gained is equal to the rate of energy lost for each surface in the enclosure. Steady state constraints for the solid bed and gas, wall, and flame are discussed below in Sections 6.1.1, 6.1.2, and 6.1.3.

6.1.1 <u>Temperature Convergence Criteria for the Solid Bed and Gas</u>

There are two ways in which the temperature of the solid or gas can be calculated to estimate the temperatures within <u>any</u> section of the kiln and how it affects the temperature to be used in the next section:

(1) The gas or solid temperature can be specified as the inlet temperature and the resulting final temperature determined by the heat absorbed by the gas or solid at the specified inlet temperatures in that section of the kiln can be used as the temperature in the next section, or

(2) The temperature of the solid or gas in the section can be specified such that the heat absorbed by the gas or solid bed is sufficient to raise the gas or solid bed from the inlet temperatures to the specified temperature of the gas or solid.

The heat transfer is different depending on whether the heat is transferred to a hot or cold body. The latter method is thought to be better represent the actual situation, recognizing that either method is approximate. The program references the value of the heat transferred to the solid bed or gas and calculates how much the temperature of the solid bed or gas would increase or decrease. The 'average' temperature of the solid bed or gas is determined when the temperature input matches the resulting temperature of the solid bed or gas calculated by the program. The solid bed and gas will enter a given section at an initial temperature, absorb or lose heat, and exit at a different final temperature. In the first method, the inlet temperatures maybe much different than the actual gas and solid temperatures in a given section, and thus can result in unreasonably high heat transfer. The latter method is a type of average of the initial and final temperatures as calculated by the first method. The later method is preferred for the following reasons:

(1) The gas and solid bed heat up very rapidly, and the use of the entering temperatures in the first section result in unreasonably high gas and solid bed temperatures.

(2) The solid bed is generally modeled as a well mixed bed (Brimacombe[3]) even though it absorbs heat through the outer surface of the bed which is thought to be hotter than the inner portion of the bed (Watkinson)[42]. That is, the bed material acts as an insulator, which allows the surface of the bed to heat up more rapidly than the interior. Thus, the use of an 'average' temperature higher than the entering

temperature models the physical behavior more closely than an initial or final temperature would.

6.1.2 Wall Balance

The assumption of steady state operation requires that the temperature for a given point in the system remains constant. From this constraint, the net rate at which the wall absorbs heat must equal the rate heat is conducted through the wall and lost to the ambient surroundings by convection and radiation (see Fig. 5.1-1). The heat lost from the shell is included in the wall balance. In this manner, the temperature of the wall is determined when the heat balance for the wall is zero. That is, the net heat to the wall from inside the kiln minus the heat lost through the wall to the outside is zero.

6.1.3 Flame Balance

Considering next the flame region in a rotary kiln, the rate at which the flame loses heat to the surrounding gas and enclosure surfaces is balanced by the net fuel combustion heat release rate in the flame. The temperature of the flame in any section is determined by the basic condition that the rate of heat entering that section is equal to the rate of heat leaving that section. The heat leaving is the net heat transferred from the flame to the surrounding gas, solid bed, and wall. The heat entering is the heat of combustion minus the heat required to heat the air and reaction products and unburned air and fuel components to the temperature of that section of the flame.

An overall heat and mass balance balance of the flame region developed by David Pitts of IT Corp.[44] was modified to be used as the flame balance in the present work. The heat and mass balance program is listed in Appendix E The present calculations consider only fuel oil to be combusted in the balance, however, different fuel compositions could be treated by the balance. The balance calculates the heat of combustion for the fuel specified composition and the mass and enthalpy of the resulting combustion gases. The primary inputs used in the balance include:

(1) fuel composition,

(2) burner excess air,

(3) flame heat loss,

(4) flame temperature, and

(5) fuel firing rate, lb/hr.

The enthalpy calculation is referred to a standard temperature of 60°F. The inputs to the balance are adjusted until the 'heat in' equals the 'heat out'. In the present work, the temperature of the flame was adjusted by the iteration process in the program to satisfy this condition.

The flame provides all the heat to the system, and the flame heat loss must include:

(1) the heat transferred to the gas, wall, and the solid bed,

(2) heat required to heat up the entrained air to the temperature of the flame,

(3) the heat required to compensate for any unburned fuel or burner air remaining after the first section. (The fuel and

air in the burner not combusted in the first section is vaporized or heated to the flame temperature of the first section. The heat required to vaporize the fuel is added to the heat loss in the first section and credited to the heat loss calculation for the second section of the flame region balance), and

(4) the heat lost from the kiln shell. (This is equal to the heat absorbed by the inner wall).

The flame heat loss is a formula in the program which sums up these above heat losses. The ''correct'' flame temperature T_{f1} is determined when:

(1) the heat lost by the flame is equal to the heat released in that section of the flame, and

(2) the temperature of the gas, wall, and solid bed are such that the heat lost by the flame equals the heat gained by the solid bed, wall, and gas.

6.2 Co-current and Countercurrent Kiln Operation

In industrial practice, the principal interest in developing a heat transfer model is to calculate the temperature profile of the solid bed and the exit temperature of the gas for a given length kiln, or to estimate the length of the kiln required to obtain some exit temperature of the gas and solids. The temperature profile of the solid bed is in part determined by whether the kiln solid feed is operated with co-current flow of the gas, ''co-current operation'', or with countercurrent gas flow, ''countercurrent operation''. Either mode of operation can be treated by the model developed.

If the kiln is operated co-currently, the solid bed is heated up rapidly by the flame early in its progression through the kiln: this operation allows the solid bed to ''cook'' at a high temperature for a longer section of the kiln than counter current operation would allow. However the co-current operation of a kiln is not as efficient in heating the solid bed as a countercurrent kiln because the temperature difference between the gas phase and the solid bed decreases rapidly as the solid bed is heated, resulting in poor heat transfer at the exit end of the kiln. In countercurrent operation, the temperature difference between the gas and solid bed is optimized and allows higher exit temperatures of the solid bed to be obtained more efficiently than with co-current operation. For a given kiln and firing rate, countercurrent operation will yield a higher exit temperature of the solids in the kiln. Alternatively it would allow use of less fuel to meet the same exit solids temperature, a smaller kiln, or higher through-put of solids if the gas-to-solids heat transfer is the limiting factor in the kiln.

The operation of a countercurrent kiln is controlled principally by the following variables,

(1) kiln length,

(2) fuel firing rate,

(3) solid feed rate, and

(4) exit solid bed temperature.

If the first three variables are specified, the exit solid bed temperature (T_{sx}) is calculated by a trial and error process. An initial T_{sx} is assumed and the program calculates the inlet solid bed temperature (T_{si}). If T_{si} does not match the known T_{si}, theT_{sx} is adjusted to give a closer match of the calculated with the known T_{si}. This process is repeated until the calculated T_{si} matches the known T_{si}. In this process, the temperature profile of the kiln will have been determined. (For the indirect-fired kiln, which is operated counter-currently, calculations to estimate the temperature profile are made in the same way).

For the present calculation, the kiln was operated co-currently because the experimental data available to verify the model were taken from a kiln which operated co-currently. For co-current operation, the exit temperatures of the solid bed and gas can be calculated directly (without a trial and error process) for a given kiln geometry., firing rate, and the entering solid and gas temperatures.

6.3 Calculation of the Temperature Profile in the Flame Region

The calculation of the temperature profile in the flame region is strongly influenced by the assumptions made regarding the recirculation and entrainment of combustion gases. In section 3.1 and 3.3, reasons are given for subdividing the flame into two sections and for assuming that twice as much gas is entrained in the second section as in the first section of the flame. The ratio of the mass of gas recirculated to the mass of gas fired through the burner is determined from the Thring and

Newby correlation (see Appendix A). For other kiln designs, this ratio and the fraction of gases entrained in each section are variable inputs in the program.

The gas in the flame region surrounding the flame of the kiln is heated simultaneously by the thermal convection (mixing) due to gas recirculation and by radiation heat transfer in the kiln from the flame and wall. The exact effect of these two factors on the gas temperature calculation depends upon whether the mixing or the radiant heat transfer is calculated first. If the flame radiates heat to the gas before it is heated by mixing, the mixed gas would be hotter. It was assumed that the gases are first mixed (resulting in a ''mixed gas'' temperature) and then heated by radiant heat transfer from the flame. This order of calculation maximizes the effect of gas recirculation on the gas temperature, while the opposite order would maximize heat transfer by radiation.

The final temperature of the flame and of the gas surrounding the flame in each section is determined in four steps:

(1) The first trial temperatures of the gas surrounding the flame in each section are initially estimated.

(2) An enthalpy balance for the section calculates an HMB (heat and mass balance) temperature based on the masses and temperatures of gases entering and exiting it (see Fig.3.1.2-1).

(3) From this temperature, the gas is heated further by heat transfer in the kiln to reach the temperature of the gas entering the next section.

(4) If the overall balance of the flame region is not satisfied, these new gas temperatures are adjusted, and the process is repeated.

For the first section of the gas in the flame region of the gas surrounding the flame the procedure is to:

(1) Estimate the temperature of the gas T_{g2} in the second section and the temperature of the gas T_{g3} recirculated to the second section. An overall kiln balance for the flame region is used to provide an estimate of the temperature of the gases T_{g3} recirculated to the second section taking into account the shell heat loss and the solid bed temperature at the end of the flame region.

(2) Calculate the enthalpy balance temperature T_{g1} of the gas mixture in the first section, and then

(3) Calculate the heat absorbed by the gas from the radiation balance.

The resulting temperature is then used as the T_{g1} temperature going into the second gas section. (See Fig.3.1.2-1 block diagram). This procedure is illustrated by the calculational flow diagram of Fig. 6.0-1.

For the second gas section, the temperature of the gas is determined by

(1) calculating the enthalpy balance temperature T_{g2} of the

gas mixture in the second section (the calculated gas temperature T_{g1} from section 1 and the calculated temperature of the hot recirculated gases T_{g3} from the end of the flame region),

(2) calculating the heat absorbed by the gas from the flame and wall from the radiation balance using the mixed gas temperature T_{g2} as the initial temperature.

The resulting calculated gas temperature T_{g2} of the second section is then compared to the temperature initially estimated in the second section and the temperature of the gases T_{g3} downstream of the flame recirculated to the second section is calculated based on the mass and temperature of T_{g2} and T_{f2} exiting the flame region. If the calculated temperatures do not match those initially estimated, then the procedure is repeated using the new calculated value for the second gas temperature T_{g2} and the gas temperature T_{g3} exiting the flame region is recalculated using the overall balance for the flame region. The procedure is repeated until the trial temperatures used match the previous gas temperatures used. The entire procedure takes about five iterations of the trial gas temperature estimated in the second section before the calculated gas temperatures and previous trial gas temperatures are within a degree. This procedure is discussed in further detail in Appendix B.

Dividing the flame region into more than two sections would involve a similar procedure, but the calculational time involved would be considerably more. Two sections for the flame region are considered sufficient in light of the accuracy of other parameters and assumptions used in such models. If one flame section is used, the (above) procedure calculates the temperature of the gas in the flame region easily with only one or two iterations of the exit gas temperature leaving the flame region. The variation in the heat transfer results caused by treating the flame region as one or two sections is discussed in Section 8.0, Results and Discussion.

6.4 Kiln Modeled with Flame Absent from View of the Enclosure

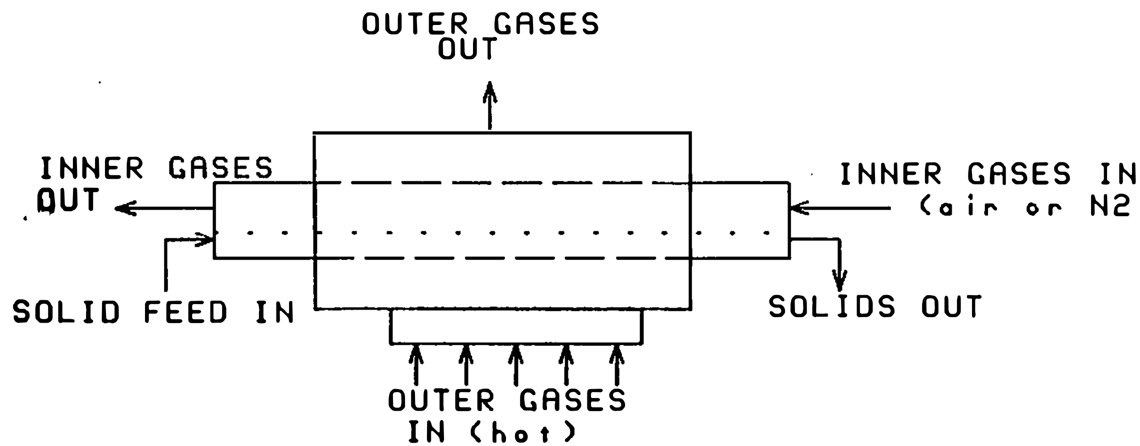
The case where a flame is not in direct view of the kiln enclosure may be modeled using the radiation balance as presented by Gorog for gas radiation only, with convective and conductive modes of heat transfer added. This case occurs when the flame is enclosed or shielded from direct view of the kiln enclosure by a flame shroud principally to ensure the solid bed is not ''burnt'' by direct radiation from the flame. Generally, the flame shroud/burner assembly is mounted outside of the kiln and the hot gases are fired into the kiln where heat is supplied to the kiln by the gas radiation only, without a flame, as in the gas region of a direct-fired kiln. The mass balance in the program is used to calculate the gas temperature based on the available heat released in the gas and the heat lost to the wall and solid bed, and an enthalpy balance is used (as in the gas region of the kiln) to determine the gas temperature if heat is not released. (For the gas region of the direct-fired kiln, heat is not released in the gas phase, and the temperature of the gas is defined such that the heat lost by the gas lowers the gas temperature by the enthalpy difference between the gas temperature of the last section and the present section). The procedure to calculate the temperatures for the wall and solid bed are treated as before.

7.0 INDIRECT-FIRED KILN MODEL AND PROGRAM DEVELOPMENT

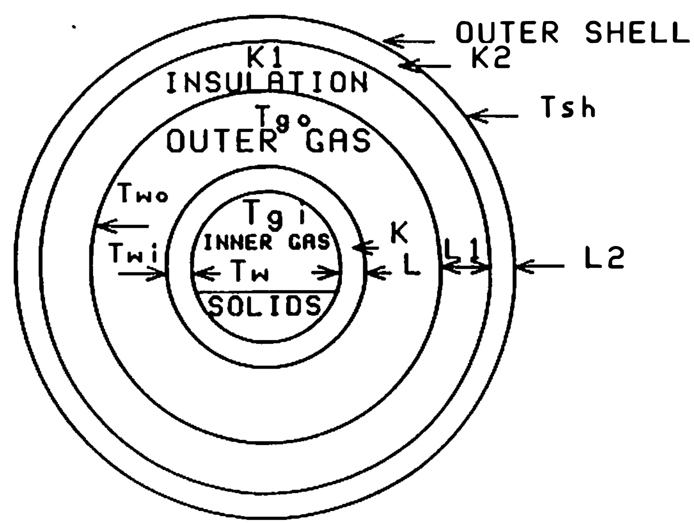
Since indirect-fired kilns are used in many industrial processes, the present heat transfer model has been extended to provide an approximate treatment of heat transfer in indirect-fired kilns. No previous heat transfer models of indirect-fired kilns have been found in the literature.

The configuration of the indirect-fired (IDF) kiln model is shown in Fig. 7.0-1a (side view) and Fig. 7.0-1b (end view). The heat transfer model used two separate heat balances (see Fig. 7.0-2). In the first balance, heat is transferred by radiation and convection from the burning fuel to the outer wall of the inner shell. Radiation heat transfer directly from the flame is neglected. About two thirds of the combustion heat is carried out by the outer shell exit combustion gas and by conduction through the outer shell wall for the typical IDF kiln. In the second heat balance, the heat entering the inner shell wall at T_{wi} leaves the inner shell wall at T_w and heats the solid bed to T_s by radiation, conduction, and convection. Thus the heat transferred to the inner shell from the outer gas is equal to the heat transferred to the solid bed (plus a small part to the inner gas).

The temperature gradient through the inner shell wall (T_{wi}-T_w) adjusts so that the amount of heat transferred from the outer gas to the inner shell at T_{wi} is equal to the heat transferred from the inner wall of the inner shell at T_w to the solid bed and inner shell gas. This amount of heat is also,



SIDE VIEW OF IDF KILN



CROSSECTION OF IDF KILN

Figure 7.0-1. Side View and Crossection of IDF Kiln

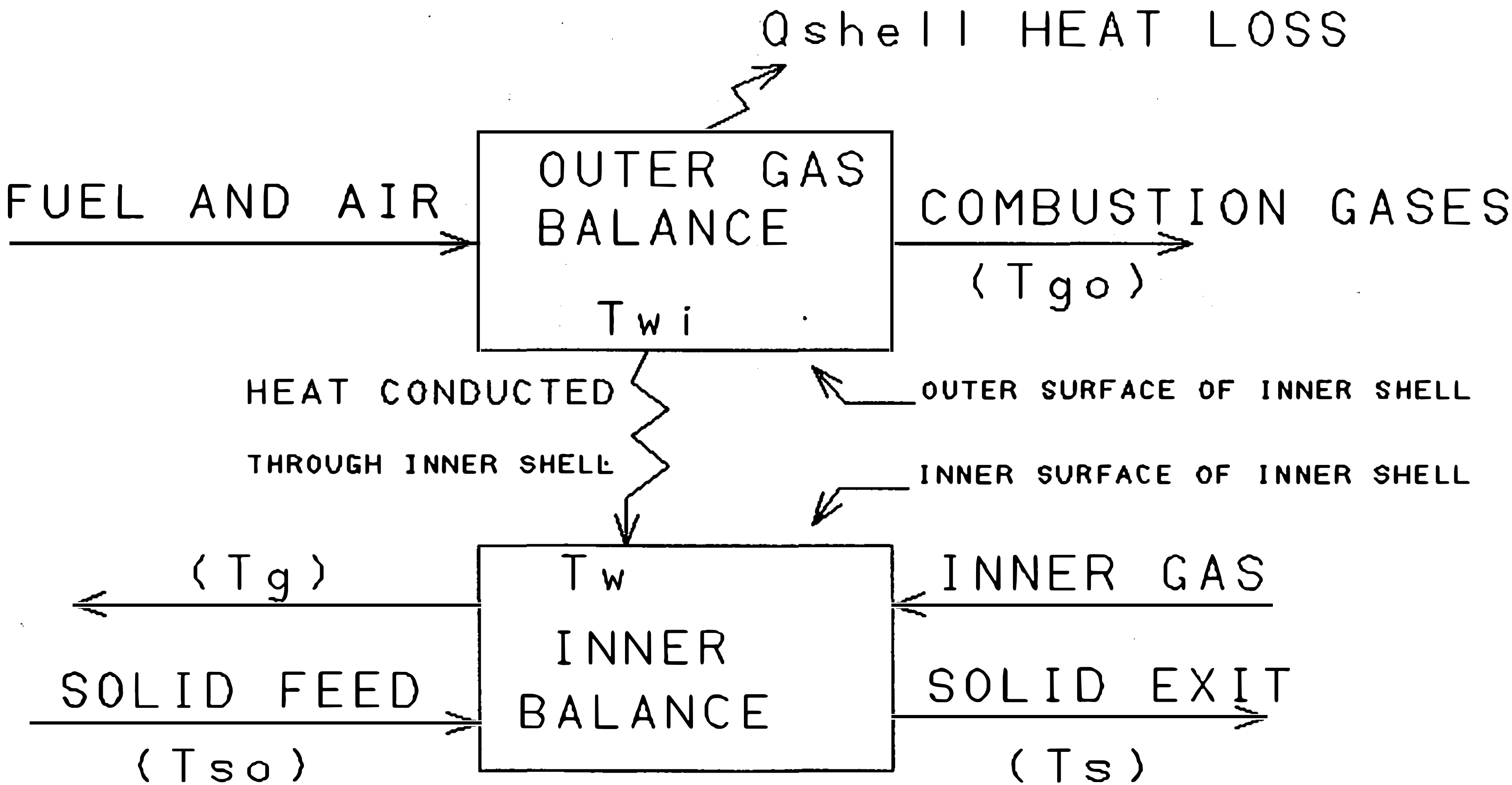


Figure 7.0-2. Indirect Fired Kiln Balances

of course, the same as the quantity moving through the inner shell under the gradient (T_{wi}-T_w).

The kiln is divided into uniform longitudinal sections for each element of which (walls, gases, and solid bed) constant temperature and surface properties were assumed over the length of each zone, as with the direct-fired kiln. This treatment provides a reasonable approximation for a direct-fired kiln, but is very approximate for an IDF kiln, because of the large angular gas temperature gradient that exists in the outer gas between the bottom and top of the kiln. An IDF kiln is fired at the bottom between the inner and outer walls of the kiln, and heat is transferred to the inner shell as the hot gases rise around the sides of the inner shell.

An estimate of the gas temperature at the bottom may be based on a heat and mass balance assuming that a typical kiln is fired with approximately 25% excess air (2600°F for the adiabatic case). A vendor of IDF kilns[45] has reported that the temperature of the outer gas leaving the top of the kiln is generally in the range of 1600 to 1800°F. The resulting temperature gradient between the top and bottom of the kiln thus is 800 to 1000°F. The outer gas temperature gradient results in a corresponding inner shell temperature gradient between the top and bottom, reported by the kiln vendor to be 200 to 300°F. To make more accurate allowance for these temperature gradients, further subdivision of the axial sections into angular sections would be required. For this work, it was assumed that heat transfer from the outer gas to the inner shell could be characterized by a single 'average' temperature of the outer gas, intermediate between the top and bottom temperatures. This intermediate gas temperature in turn was assumed to correspond to a single intermediate inner wall temperature.

Additional vendor information[45] indicated (1) that, because of material considerations, the upper practical limit of the average temperature of the shell surface in contact with the outer gas was approximately 1400°F, and (2) that the exit temperature (T_{si}) of the solid bed ranged up to within 200°F of the temperature of the inner surface of the inner shell.

The case chosen for modeling was the use of of an IDF kiln in the thermal treatment of damp soil slightly contaminated with hazardous organic chemical wastes. Kiln characteristics and operating parameters were taken to be those of a commercially available IDF kiln used primarily for heating dry solids and for which some operating characteristics were available. Unfortunately a complete set of empirical data was not available, and it was not possible to run the model computations for a realistic set of operating conditions and then compare the calculated with the actual results. Thus this model is unproven, but it is presented here as a logical extension of the direct-fired model discussed earlier. The kiln parameters and operating conditions needed for the calculation of the bed temperature profile were given selected values that appeared reasonable for thermally treating damp contaminated soil. In this example, the fuel burning rate in each kiln section was chosen to yield the same 'average' outer gas temperature (2200

F) in each section. This required a higher fuel burning rate in the solid feed end of the kiln and progressively lower rates toward the bed exit end.

The convergence method used to determine the temperature profile for the IDF kiln was similar to that used for the gas region of the direct-fired kiln with the added condition that the heat transferred to the inner shell from the outer gas equaled the heat transferred through the inner shell to the inner gas and solid bed. The temperature of the inner wall of the inner shell determined how much heat was transferred to the inner gas and solid bed. The unique set of temperatures for a given section of the kiln was again determined by a trial and error procedure like that used in the direct-fired kiln. The heat transfer calculations were performed for an IDF kiln operated with an inner gas flow countercurrent to that of the solid bed. For the reasons discussed in Section 6.7, the iteration procedure to determine the kiln temperature profile was started at the exit end of the kiln. The computer program listing for IDF kiln operation in this mode is given in Appendix F. The resulting temperature profiles are shown in Fig. 7.0-3 and Table 7.0-1. These profiles show the following:

(1) The solid bed temperature, T_s, remains constant at 212 F until its water content has been evaporated. Then the T_s rises at an approximately constant rate to its exit temperature, 1130°F.

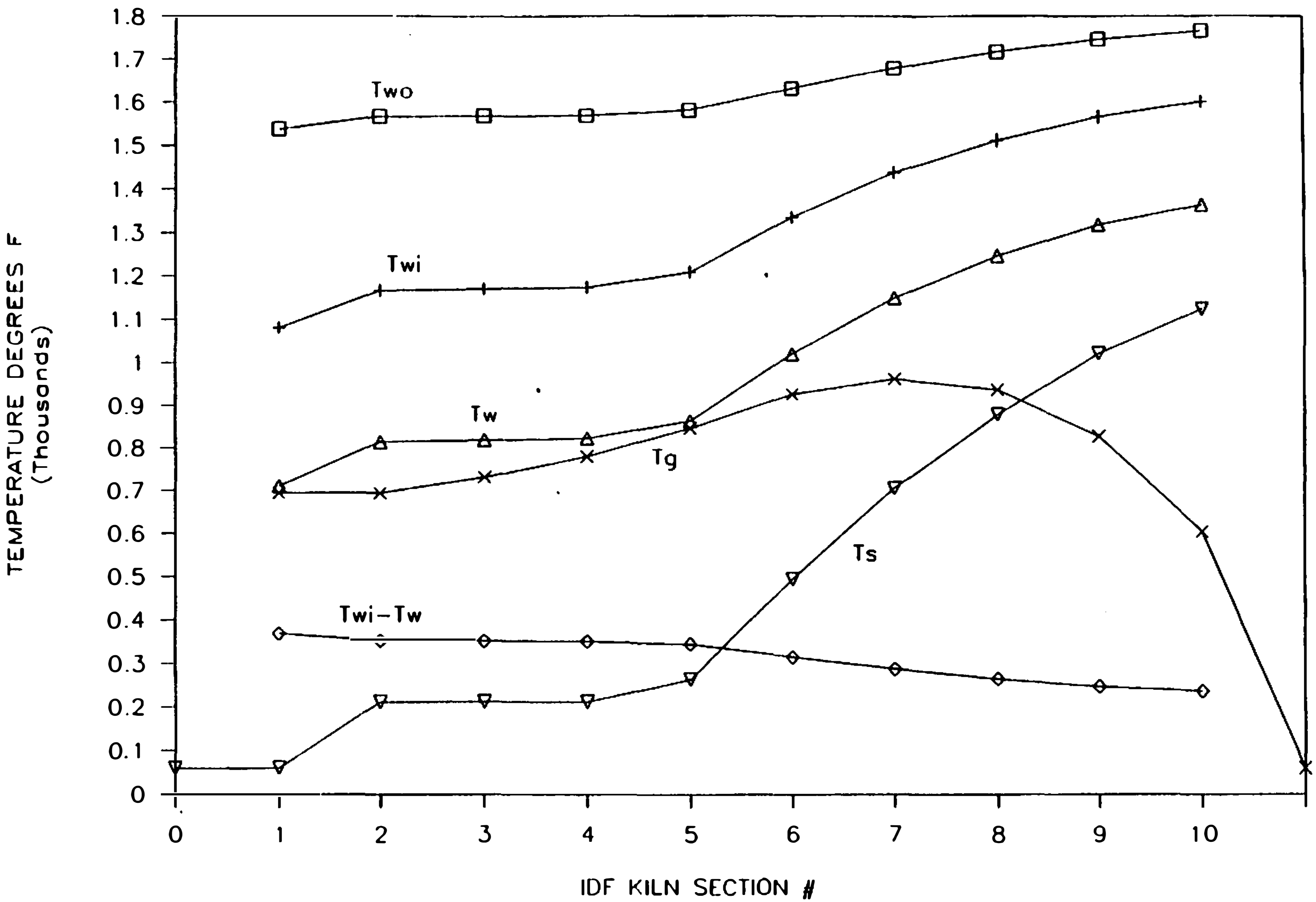


Figure 7.0-3. Calculated IDF Kiln Temperature Profiles

Table 7.0-1. Calculated IDF Kiln Temperature Profiles

SECTION #	Two	Twi	Twi-Tw	Tw	Tg
1	1540	1081	369	712	696
2	1568	1168	353	815	696
3	1569	1171	352	819	732
4	1570	1175	351	823	781
5	1583	1210	345	865	847
6	1633	1337	316	1021	927
7	1680	1439	288	1151	963
8	1717	1514	265	1248	937
9	1746	1568	248	1320	828
10	1766	1603	237	1365	606

(2) During the drying of the solid bed in kiln sections 2 to 5, all of the other temperatures (T_{wo}, T_{wi}, and T_w) except the inner shell gas temperature also remain relatively constant, and subsequent kiln sections then rise monotonically toward their values at the solid exit end of the kiln.

(3) The inner gas, which enters the kiln at the solid exit end at low temperature, is heated to a maximum temperature in section 7, then is cooled by the cooler solid bed as its water evaporates.

(4) The value of (T_{wi}-T_w), which is roughly proportional to the fuel burning rate, remains constant until the water content of the solid bed has been vaporized, and then decreases toward the solid exit end of the kiln.

The calculated temperature profiles agree qualitatively with what might be expected intuitively. However for the vendor-described kiln as modeled, sufficient heat could not be transferred to dry the bed and heat it to 1100°F in the assumed length of kiln without exceeding the vendor-specified limit of the inner shell temperature. For the assumed outer gas temperature of 2200°F, the calculated outer wall temperature of the inner shell rose above the allowable limit the vendor reported[45] (1400°F), reaching 1600°F at section 10. This could be avoided by lowering the outer gas temperature, but then less heat would be transferred to the solid bed and it could not be heated to the desired 1100°F. A further difficulty encountered was that it was necessary in the model to assume unrealistically high conductive heat transfer from the inner wall of the inner shell to the solid bed in order to achieve a bed temperature of 1100°F at the exit end of the kiln for the kiln length used. The use of dry soil feed would agree better with the vendor suggested kiln operating characteristics. The model indicates for damp soils, that either a longer kiln or a lower soil feed rate would be required to reach exit bed temperatures of 1100°F estimated by the vendor. As mentioned above, empirical (operating) data from an IDF kiln complete enough to verify the model and computer program were not found in the literature.

This example shows how the model may be used to determine the overall shape of the temperature profiles in an IDF kiln and to predict the effect of changing kiln parameters and operating conditions. No other model has been described in the literature to provide this type of design information for IDF kilns.

8.0 RESULTS AND DISCUSSION

The results are discussed in four main sections. These are: (1) verification of the basic heat transfer model, (2) the modeling of the flame region including recirculation and entrainment, (3) the derivation of gas emissivities from real gas data, and (4) the application of the model to an IDF kiln.

8.1 Overall Heat Transfer Model Verification

The heat transfer model and computer program developed were verified using data from the operation of the ERRU kiln[25], a direct-fired kiln used for incinerating soil contaminated with trace levels of dioxin. The operating data used for modeling the ERRU kiln are listed in Table 8.1-1 and include information on:

(1) the physical configuration of the kiln (dimensions, refractory type and thickness, and shell thickness),

(2) solid bed characteristics including feed rate, % moisture, heat capacity, and % fill in the kiln,

(3) fuel (No. 2 fuel oil) and air feed rates, and

(4) the exit temperatures of the gas and solid bed, and measured approximate shell temperatures.

(5) the convective and conductive heat transfer coefficient values

The model predictions of the temperature profiles for the flame, wall, solid bed, and shell are shown in Fig. 8.1-1 and Table 8.1-2. The computer program listing for these calculations is

Table 8.1-1. Operating Data from ERRU Kiln

Parameter	Value
Kiln Diameter, meters	1.32
Kiln Length, meters	4.87
Fire Brick, inches	4
Fire Brick K-value, Btu/ft2F/in	5.5
Insulating Brick, inches	2
Insulating Brick K-value, Btu/ft2F/in	2
Radiation Parameter	
Solid Bed Solid Angle, Degrees	80
Solid Bed Emissivity	0.8
Wall Emissivity	0.8
Shell Emissivity	0.7
Conv. & Cond. Heat Transfer Coeficient	
Wall to Solid Bed, W/m2K	50
Gas to Solid Bed, W/m2K	50
Gas to Wall, W/m2K	20
Shell to Ambient (conv.), W/m2K	10
Shell to Ambient (rad.), W/m2K	9
Operating Parameters	
Soil Feed Rate, lb/hr	1335
Soil % H2O	10.1%
Soil Heat Capacity, Cp Btu/lbF	0.26
% Excess Air	65.6%
Fuel Oil Firing Rate, lb/hr	178
Solid Bed Exit Temperature, F	1600
Gas Exit Temperature, F	1840

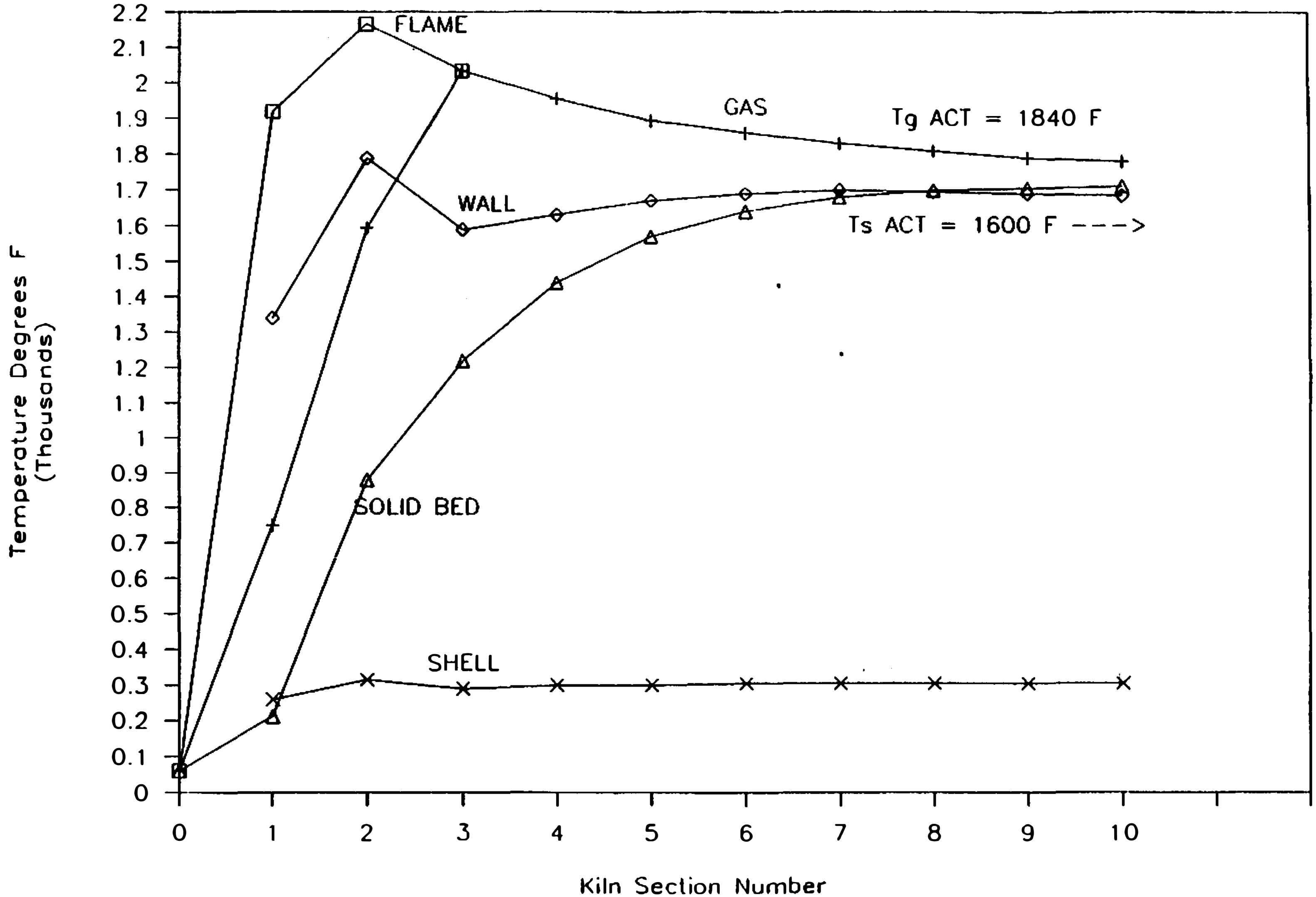


Figure 8.1-1. Calculated ERRU Kiln Temperature Profiles

Table 8.1-2. Calculated ERRU Direct Fired Kiln Temperature Profiles

SECTION #	Tf	Tg	Tw	Ts	Tsh
0	60	60		60	
1	1920	750	1340	212	260
2	2165	1595	1790	880	315
3	2035	2035	1590	1220	290
4		1955	1630	1440	300
5		1895	1670	1570	300
6		1860	1690	1640	305
7		1830	1700	1680	305
8		1810	1695	1700	305
9		1790	1690	1705	305
10		1780	1685	1710	305

given in Appendix E. The model assumes a two section flame region with the mass of recirculated gas set equal to the mass fired through the burner, in accordance with the discussion of recirculation effects given in Section 3.3. For the experimental data of the gas and solid bed, only the temperatures from the exit of the kiln were available for comparison to the model predictions. Shell temperature data were available at several points along the kiln shell.

As shown in Fig. 8.1-1, satisfactory agreement was obtained between the calculated and observed shell temperatures and the exit temperatures of the gas and solid bed. The predicted temperature profiles indicate the model slightly over-predicts the heat transferred from the freeboard gases to the solid bed, resulting in a higher solid bed temperature and lower exit gas temperature than those measured for the ERRU kiln. The shell temperatures are very close to the measured values, particulsrly in the flame region.

The values of all parameters used in the heat transfer model were obtained from the literature or experimental data, and are listed in Table 8.1-1. Conductive and convective heat transfer coefficient values from the gas and wall to the solid bed were selected at the lower end of ranges reported in the literature to obtain slightly better agreement between actual and predicted solid bed exit temperatures.

8.2 <u>Heat Transfer Modeling of the Flame Region</u>

The modeling of heat transfer in the flame region was discussed in Section 3.0. The three-foot flame region of the

EERU kiln[35] was modeled first considering the flame region as one section, and then as two sections. For each case, the heat transfer was treated with and without consideration of entrainment and recirculation of combustion gases. These heat transfer results are shown in Table 8.2-1.

The gas temperatures calculated with and without consideration of recirculated gases are significantly different. The temperature of the gas surrounding the flame increases as recirculation increases , while the flame temperature decreases. Also the lower flame temperature resulting from entrainment of gases results in less heat transfer to the solid bed. The gas temperature calculated for the one section case was intermediate between the gas section temperatures calculated for the two section case. Similarly, an intermediate flame temperature resulted for the single section case. However, approximately the same solid bed temperature and gas temperature leaving the flame region were obtained regardless whether one or two sections were used. This result indicates that the coarseness of kiln zoning did not strongly affect the heat transfer to the solid bed and the exit temperatures in the flame region are not stongly sensitive to segmentation and recirculation in the flame region. Clearly the two section representation of the flame region is more realistic since it can show the existence of a temperature gradient in the flame region.

Table 8.2-1. Results of Calculations in the Flame Region with 1 or 2 Sections and with or without Recirculation of Combustion gases

Case Tested	Surface	Section 1	Section 2	Entering Gas Section Temp	Section 1 Qi (Btu/hr)	Section 2 Qi (Btu/hr)	Flame Region Qi total (Btu/hr)
2 Sections w/o Recirculation	Tf	2,157	2,550		386,749	584,965	971,714
	Tg	393	938	1,972	(156,681)	(277,488)	(434,169)
	Tw	1,545	1,949		(7)	0	(7)
	Ts	281	1,213		(211,964)	(283,145)	(495,109)
	Tsh	286	344		(18,112)	(24,338)	(42,450)
					(15)	(6)	(21)
2 Sections with Recirculation	Tf	1,920	2,168		265,739	287,686	553,425
	Tg	750	1,594	2,038	(86,110)	(32,434)	(118,544)
	Tw	1,339	1,790		(6)	(68)	(74)
	Ts	212	877		(164,100)	(234,000)	(398,100)
	Tsh	260	315		(15,487)	(21,188)	(36,675)
					36	(4)	32
1 Sections w/ Recirculation	Tf	2,126					765,037
	Tg	1,464		1,977			(235,059)
	Tw	1,937					177
	Ts	1,153					(484,062)
	Tsh	332					(46,098)
							0
1 Sections w/o Recirculation	Tf	2,352					1,168,683
	Tg	1,182		1,928			(563,561)
	Tw	2,127					(133)
	Ts	1,377					(554,022)
	Tsh	353					(50,967)
							0

8.3 Emissivity of Gas

In the present work the gas emissivity of CO_2 and water was calculated using Hottel's data[16] for emissivity. Hottel's data were regressed using a least squares method which enabled emissivity of any partial pressure of CO_2 and H_2O to be calculated for a wide range of temperatures and beam lengths. The calculated emissivity of the combustion gases is compared to Hottel's experimental data[16] in Table 4.5-4 for various temperatures and beam lengths of interest for CO_2 and H_2O. This table indicates good agreement with the data of Hottel. The data regression was carried out using the computer program listed in Appendix G.

8.4 Indirect-Fired Kiln Heat Transfer Model

Section 7.0 showed how the present model developed could be used for an approximate treatment of heat transfer in an indirect-fired kiln (IDF). The computer program listing for these calculations is shown in Appendix G. Since a sufficiently complete set of experimental data is not available for comparison, the predictive value of this model for an IDF kiln could not be accurately assessed. The model predictions of the exit bed temperature are somewhat lower than those based on vendor predictions of the performance of IDF kilns[48]. The vendor's predictive model assumes that approximately 1/3 of the combustion heat is transferred to the solid bed. This assumption is unduly optimistic for the final stages of heating the bed. This accounts in part at least for the different predictions between these two models. In spite of the very approximate nature of its modeling, the model was able to indicate the ways in which solid bed and gas temperature profiles would depend upon kiln parameters and operating conditions.

9.0 SUMMARY AND CONCLUSIONS

An improved heat transfer model has been developed for a direct-fired rotary kiln. The model can be used to verify kiln design, to optimize operating conditions, to predict the temperature history of the solids, and to evaluate if local areas of the kiln will be overheated. The treatment of radiant heat transfer was based on the Reflection Method developed by Succec and applied by Gorog, and was extended to account for radiation from a flame. Some elements of the Resistive Network Method and Zone Method were incorporated in the model. This method results in a more straightforward and flexible treatment of radiant heat transfer than other methods of analysis. The model also accounts for conductive and convective heat transfer within the kiln and heat conducted through the kiln wall and lost from the outer kiln shell to the ambient surroundings.

The model divides the kiln into a flame region where the flame is present, plus a downstream gas region. The flame and gas regions are each subdivided longitudinally into kiln sections of equal length. A new method was devised to model the grey body emissivity of an axially centered flame of given area. It was treated as equivalent to a black body of reduced area. This treatment greatly simplified the calculation of radiant heat transfer to and from the flame. A method was devised for calculating the gas transmissivity for its own radiation in the Reflection Method. The model also includes an approximate treatment of the recirculation and entrainment of combustion gas in the flame region, and assumes plug flow downstream of the flame region. A regression method was developed for calculating the emissivity of combustion gases of varying CO_2 and H_2O concentrations based on Hottel's real gas data. The temperature and heat transferred to or from the flame, gas, wall, and solid bed in each axial section of the kiln is calculated using the Reflection Method by simultaneously solving a set of algebraic expressions involving the emissivity, area, and radiative (geometrical) view factors for the various surfaces in the kiln. The model was verified with a computer program written in LOTUS 1-2-3 using a set of operating data from a direct-fired kiln used for the incineration of lightly contaminated soil. The model yielded good agreement between the calculated and reported values of the solid and gas exit temperatures as shown in Fig. 8.1-1 and Table 8.1-1. The percent error for the estimated solids exit temperature was 6.8 and for the gas was -3.2.

The new heat transfer model was also extended to provide an approximate treatment of heat transfer in IDF kilns. The model used two separate heat balances to (1) estimate the heat transferred from burning fuel in the outer gas to the outer surface of the inner shell, and (2) the heat transferred through the inner shell and radiated to the solid bed and inner gas. As with the direct-fired kiln, the kiln was divided into uniform longitudinal sections, each with constant temperatures and surface properties. The use of a constant outer gas temperature is only approximate because of the steep temperature gradient that exists between the bottom temperature where the fuel combustion occurs and the top temperature where the combustion gases exit. Model calculations for a hypothetical data set (no actual data were available) indicated approximate agreement with vendor reported kiln characteristics and temperature profiles.

This model is the first treatment of heat transfer in an IDF kiln reported in the literature.

9.1 General Heat Transfer Model Developments

The radiation balance developed can be applied to any enclosure with two grey surfaces (e.g., wall and solid bed) and one black body or axially centered grey body (e.g., flame) with a participating gas of varying CO_2 and H_2O concentrations. The temperatures of the three surfaces and the gas determines the heat flow within the enclosure. Convective heat transfer from the gas to both grey surfaces (the solid bed and wall), and conductive heat transfer between the grey surfaces is considered. All parameters required for calculating the heat distribution are variables which can be input in the program, and they can be modified for different geometries, fuel, air, solid bed feed rate, surface properties, and gas compositions. Heat loss by conduction through the enclosure shell is estimated for a kiln wall constructed of 2 layers of insulating material and the outer shell. Heat is lost from the outer shell by convection and radiation to the ambient surroundings.

9.2 Simplifying Assumptions

To simplify the development of the heat transfer model, a number of assumptions were necessary. These include the following: (1) the neglect of axial radiation, (2) the use of a constant circumferential wall temperature, (3) an approximate treatment of recirculation and entrainment of combustion gases in the flame region, (4) neglect of kiln end effects, (5) a well mixed solid bed of constant temperature within each axial zone, (6) neglect of the effect of coarse kiln zoning of the kiln, (7) constant 'average' surface and gas temperatures in each zone, and (8) constant emissivity of the flame over its length. Approximate estimates were made for the effects of these assumptions on the uncertainties of results calculated by the model.

10.0 RECOMMENDATIONS FOR FURTHER WORK

(1) While there is a great amount of information published on combustion technology and heat transfer, there is a lack of detailed information in the open literature on the physical parameters and operating conditions for direct-fired rotary kilns. It would be of great value in verifying the validity of kiln heat transfer models if such detailed experimental data were determined and reported.

(2) The accuracy of the model could be improved by extending it to include the treatment of the effects of the following phenomena: (1) effects of soot and entrained dust concentrations on the flame and gas emissivities, (2) more detailed zoning of the flame region as it effects recirculation and entrainment, heat and mass balance, gas compositions, and temperature profile in each zone, (3) using grey/clear gas models to determine the emissivities of CO_2-H_2O mixtures of varying compositions, and (4) a solid bed containing combustible material.

(3) Carry out sensitivity analyses of all the assumptions listed above.

(4) For extended and repeated use of the program, a FORTRAN coded version would reduce computation time required.

(5) A heat transfer model for IDF kilns capable of treating angular surface and gas temperature gradients should be developed to provide a more accurate description of surface and gas temperatures.

REFERENCES

REFERENCES

(1) J.P. Gorog, J.K. Brimacombe, and T.N. Adams:Radiative Heat Transfer in Rotary Kilns. Metal. Trans. B,1981, Vol 12B, pp 55-70.

(2) J.P. Gorog, T.N. Adams ,and J.K. Brimacombe:Regenerative Heat Transfer in Rotary Kilns. Metal. Trans. B,1982, Vol 13B, pp 153-163.

(3) J.P. Gorog, T.N. Adams ,and J.K. Brimacombe:Heat Transfer from Flames in a Rotary Kilns. Metal. Trans. B,1982, Vol 13B, pp 153-163.

(4) B.G. Jenkins and F.D. Moles:Modelling of Heat Transfer from a Large Enclosed Flame in a Rotary Kiln. Trans I Chem. E. 1981, Vol .14B, pp.411-424.

(5) J.M. Beer:Methods for Calculating Radiative Heat Transfer from Flames in Combustors and Furnaces. 'Heat Transfer in Flames',Scripta Book Co.,Washington, D.C., 1979, pp. 30-45.

(6) W. Richter and R. Quack: A Mathematical Model of a Low-Volatile Pulverised Feul Flame. Ibid. pp. 95-109.

(7) V. Venkatatewaren and J.K. Brimacombe: Mathematical Model of the SL/Rn Direct Reduction Process. Metall. Trans. B, 1977, Vol. 8B, pp387-398.

(8) H.A. Spang: A Dynamic Model of a Cement Kiln. Automatica, 1972, Vol. 8B, pp. 309-323.

(9) A.Manitius, E. Kurcyusz, and W. Kawecki: Mathematical Model of the Aluminium Oxide Rotary Kiln. Ind. Eng. Chem. Process Des. Develop, Vol. 13, 1974, pp. 132-142.

REFERENCES (CONT)

(10) K.W. Pearce: A Heat Transfer Model for a Rotary Kilns. J. Inst. of Feul, 1973, Vol. 40, pp. 363-371.

(11) A. Sass: Simulation of the Heat-Transfer Phenomena in a Rotary Kiln. I β EC. Proc. Des. Develop., 1967, Vol. 6, pp. 532-536.

(12) J. Kern: Heat Transfer in a Rotary Heat Exchanger. Int. J. Heat Mass Transfer, 1974, Vol. 17, pp. 981-990.

(13) S.L. Wingfield, A. Prothero, and J.B. Auld: A Mathematical model of a Rotary Kiln for the Partial Reduction of Iron Ore. J. Inst. of Feul, 1974, Vol. 47, pp. 64-72.

(14) J.W. Lyons, H.S. Min, P.E. Parisot, and J.F. Paul: Experimentation with a Wet-Process Rotary Cement Kiln via the Analog Computer. I. β EC. Proc. Des. Develop., 1962, Vol. 1, pp. 29-33.

(15) W.E. Lobo and J.E. Evans: Heat Transfer in the Radiant Section of Petroleum Heaters. Trans. Am. Inst. Chem. Engrs., 1939, Vol. 35, pp. 743-778.

(16) H. Hottel and A. Saforim: Radiative Transfer'. McGraw Hill, New York, 1967, pp. 199-296.

(17) H.C. Hottel, and E.S. Cohen: Radiant Heat Transfer in a Gas Filled Enclosure: Allowance for Non-Uniformity of Gas Temperature. Amer. Inst. of Chem. Eng. J., 1958, 4, 3.

(18) A.D. Gocman, and F.C. Lockwood. Paper presented at the Fourteenth Symposium (International) on Combustion (1972).

(19) A.K.Oppenheim: Radiation Analysis by the Network Method, ASME Trans., 1956, Vol. 78.

REFERENCES (CONT)

(20) General Electric Heat Transfer Handbook: Radiant Heat Transfer. General Electric Publication, 1981, section 505.2 p.9.

(21) Ibid. Section 505 pp. 1-50.

(22) F.P. Incropera, D.P. Dewitt: 'Fundamentals of Heat Transfer'. John Wiley β Sons, 1981, pp. 570-705.

(23) F. Kreith: 'Priciples of Heat Transfer'. Intext Educational Publishers, 1973, pp. 219-308. (24) J. Succec:'Heat Transfer'. Simon and Schuster, New York, 1975, pp.233-307.

(25) J.L. Flemming, D.M. Pitts:'Evaluation of the capacity of the EPA Mobile Incineration System For Thermal Treatment of Contaminated Soil'. EPA contract No. 68-03-3069. Published by International Technology Corp., Knoxville, Tn.

(26) M.A. Field, D.W. Gill, B.B. Morgan, and P.G.W. Hawksley. Combustion of Pulverised Coal. THe British Coal Utilization Research Association, Leatherhead, 1967.

(27) M.W. Thring and M.P. Newby, Proc. 4th Int'l Symposium on Combustion, Combustion Institute, Pittsburgh, Pa.,1953, pp.719-796.

(28) B.G. Jenkins. 'Heat transfer in Rotary Cement KIlns'. Phd Thesis. University of Surrey. Guildford, Surrey. September 1976.(29) A. Craya and R. Curtet, C.R. Acad. Sci., Paris, 241:621-622, 1955.

REFERENCES (CONT)

(30) J.M. Beer, International Flame Research Foundation: The Effect of Fineness and Recirculation on Combustion of Low-Volatile Pulverized Coal. J. Inst. Fuel, 37, 286-313 (1964).(31) M. Barchilon and R. Curtet, J. Basic Eng., 86D: 777-787 (1964).

(32) H.A. Becker, H.C. Hottel, and G.C. Williams. Int. Symp. Combust., 9th, p.7, (1963).

(33) W.R. Niessen, Combustion and Incineration Processes. 1978, Marcel Decker, Inc., N.Y.,N.Y.

(34) M.W. Thring, J.M. Beer, and P.J. Foster. The Radiative Properties of Luminous Flames, Third International Heat Transfer Conference, 5, 101-111, (1966).

(35) T.R. Johnson. Application of the Zone Method of Analysis to the Calculation of Heat Transfer from Luminous Flames. University of Sheffield, Phd Thesis, 1971.

(36) A.F. Sarofim. 'Flame Emissivities: Alternative Fuels'. Alternative Hydrocarbon Fuels: Combustion and Chemical Kinetics. Vol 62 Progress in Astronautics and Aeronautics. Princeton University. Princeton, New Jersey, 1977.

(38) K.B. Lee, M.W. Thring, and J.M. Beer. On the Rate of Combustion of Soot in a Laminar Soot Flame. Combustion and Flame, 6 137-145, 1962.

(39) R.W. Young and M. Cross. Iron and Steel Making, 1976, Vol 3, p.129-137. (40) P. Weber. 'Heat Transfer in Rotary Kilns with Due Regard to Cyclic Process and Phase Formation'. Zement-Kalp -Gips. Spec. English Ed., (wiesbaden, Bauverlag GmbH.) 1963.

REFERENCES (CONT)

(41) A. Folliot. 'La Transmission de Chaleur dans le four Rotatif a Ciment'. Publication Technique No, 70, (Centre D etuudes et de Recherches de L'industrie des Liants Hydrauliques, (Paris) 1955.

(42) A.P. Watkinson and J.K Brimacombe. 'Heat transfer in a Direct-Fired Rotary: Heat Flow Results and Their Interpretation'. Metall. Trans. B, 1978, p.209-219. (43) F. Kreith. Principle of Heat Transfer. Intext Educational Publishers, 1973.

(44) D. Pitts: Unpublished Program, IT Corporation, 1985.

(45) C.E. Raymond: Private Communications, C.E. Raymond Kiln Vendor.

(46) R.H. Perry. Chemical Engineers' Handbook, 6th ed., McGraw Hill, Inc. 1984.

(47) S.H. Tscheng and A.P. Watkinson. 'Convective Heat Transfer in a Rotary Kiln'. Can. J. Eng., 1979, Vol. 57, p. 433. (48) H. Erkku. (1959). ScD. Thesis in Chem. Eng. M.I.T., Cambridge, Massachuesetts.

(49) D.B. Spaulding. 'The Art of Partial Modeling'. Ninth Symposium (International) on Combustion. The Combustion Institute (1963).

(50) F.P. Ricuo and D.B. Spaulding, J. Fluid Mech., 11:21-32 (1961).

(51) International Flame Research Foundation, IJmuiden, Holland.

APPENDICES

APPENDIX A

FLAME REGION ENTRAINMENT MODEL DEVELOPMENT

As discussed earlier in the model development (Sections 3.1-3.3) and results and discussion (Section 8.0), the recirculation of entrained gases significantly changes the temperature of the flame and the gas surrounding the flame. This appendix provides additional information on how the amount of gas recirculated varies with different operating conditions and burner configurations.

The treatment of entrainment and recirculation of gases in the flame region is based on the correlation of Thring and Newby[27], as modified by Field et al.[26]. Ricou and Spaulding[50] measured entrainment rates and determined that the mass flow rate (m_x) in the jet is linearly related to x according to the equation

$$m_x/m_o = 0.32\ (\rho_a/\rho_o)^{1/2}\ (x/do) \qquad \text{Eq. A-1}$$

This relationship holds for all values of nozzle Reynolds number greater than $2.5 * 10^4$ and for $x/do > 6$. At $x/do < 6$, the entrainment rate per unit jet length is lower, increasing progressively with distance until it stabilizes at the constant value corresponding to Eq. A1.

The correlation modified by Field et al. assumes that the the jet entrains as a free jet up to the point C (see Fig. A-1) and the total entrainment up to this point (the net recirculation flow m_r) is given by the Eq. A-2:

$$m_r = [0.32(\rho_a/\rho_o)^{1/2}\ (x-6do)/d_o\ m_o] - m_o \qquad \text{Eq. A-2}$$

This is Eq. 3.2 with the terms as defined in the text. The point C is postulated to lie midway between the point x_o where entrainment begins ($m_x = m_o$), according to Eq. A-2 and the point p (see Fig. A-1) where the envelope of an unconfined jet strikes the wall. From Eq. A-1 where $m_x = m_o$:

Fig. A-1

$x_o = (d_o/.32)(\rho_o/\rho_a)^{1/2}$ Eq.1.0-3

Assuming the jet angle of 9.7°, the jet strikes the wall at a distance x_p diameters down the duct:

$x_p = 2.925\ D$ Eq. A-4

Thus x_C is given by

$x_C = 1/2\ [\ x_p + d_o/0.32)(\rho_o/\rho_a)^{1/2}]$ Eq. A1.-5

A parameter ω is then defined:

$\omega = (d_o/D)(\rho_o/\rho_a)^{1/2}$ Eq. A-6

hence

$x_C = 1/2(x_p + D\omega/0.32)$

$= D(1.467 + \omega/0.64)$ Eq.A-7

and

$m_r/m_o = 0.47/\omega - 0.5$ Eq. A-8

Present Work -

The correlation has been modified in the present work assuming that

$x_p = D$

due to the skewed burner configuration which angles the flame from the burner toward the wall, and consequently intercepts the wall earlier than one would expect in most kilns. This results in Eq. A-7 becoming:

$x_C = D(0.5 + \omega/0.64)$, Eq. A-9

and Eq. A-8 becomes,

$m_r/m_o = 0.16/\omega - 0.5$ A-10

This last equation results in about 1/3 of the net recirculated flow as proposed by the Thring and Newby correlation due to the shorter jet length used. The values used in the resulting equation, Eq. A-10, are:

ρ_a = 0.0745 lb/ft^3 for the density of the ambient air

ρ_o = 0.0787 lb/ft^3 for the density of the fuel jet stream

D = 4 ft for the diameter of the kiln

d_o = .5 ft for the burner nozzle diameter

and

$m_r = 0.746\ m_o$ Eq. A-11

As can be seen from the form of Eq. A-1, the net entrainment is proportional to the distance from the burner along the jet axis (or kiln axis in this case). This relationship relationship is valid for distances from the burner nozzle greater than 6 nozzle diameters, $6d_o$. Less than $6d_o$, the entrainment rate is less. To account for entrainment in this distance, the rate of entrainment in the first section was assumed half of the rate in the second section. The resulting block flow diagram is shown in Fig. 3.1.2-1. Note that the gases recirculated are assumed to originate from the end of the flame region.

With the specified rate of gas entrainment in each section, the balance for the flame region can be solved. The fuel and air not combusted in the first flame section are assumed to be volatilized and heated to the temperature of the first flame section and enter the second flame section as preheated fuel and air. The heat required to preheat the fuel and air is treated as a heat loss in the first flame section and as a heat 'credit' in the second flame section. By considering

(1) the net heat release of the flame for each section

(2) the enthalpy balance of the flame region for recirculated gases.and

(3) the overall balance of the flame region, the temperatures in the flame region may be solved using the radiation balance as discussed earlier in program development and below.

APPENDIX B

Enthalpy Balance of the Flame Region

Enthalpy Balance of the Flame Region

The enthalpy balance of the flame region is presented here for a flame region which is divided into two sections and considers recirculation of combusted gases. The resulting block diagram is shown in Fig. 3.1.2-1. The flame region with recirculation of combustion gases modeled as a single section is a much simpler subset of the block flow diagram below.

Note that the overall mass balance of the flame region requires that the total mass entering the balance (the sum of the excess air and the mass fired through the burner) is equal to the mass leaving the flame region (the mass of the combustion gas plus the mass of excess air). This relationship is expressed mathematically as follows:

$$M_o + M_{xair} = M_{cp} + M_{xair}$$

This equation requires that $M_o = M_{cp}$. From this balance, it is recognized that the effect of recirculated gases can be viewed qualitatively as a partial mixing of the gas and flame sections in the flame region. The primary result of considering recirculated gases in the flame region is to increase the temperature in the gas sections and decrease the temperature in the flame sections of the flame region. These temperature changes affect the heat transfer in the flame region of the kiln. There is very little effect from recirculation downstream of the flame region, where the gases are assumed to be well mixed and of uniform temperature within each section of the gas region.

B1.0 <u>Assumptions Required for Recirculation Calculations</u>

The following assumptions are required to solve for the temperatures in the flame region:

(1) The composition and mass of the secondary excess air, M_{xair}, is constant (not mixed with the recirculated gases) in each gas section, but is allowed to come to thermal equilibrium within the gas section with the recirculated gases. This assumption is made because there is no simple way to determine the fraction of excess air directly entrained in the flame or the extent of mixing, and the composition of the excess air and recirculated gases are both primarily nitrogen. Consequently, the heat capacities of these gases are nearly the same, and error from this assumption had negligible effects on the heat or mass balance.

(2) The mass of recirculated gas, $X(M_{cp}+M_{xair})$ as seen in Fig.3.1.2-1, represented by the value m_r as calculated above in Appendix A in the modified correlation of Thring and Newby, is a variable input in the program, and is varied by specifying the fraction of the burner mass which has been estimated to be recirculated,C_r (the constant above of 0.746 in Eq. A10). The fraction X is calculated in the

program by the following equation:

$$X = C_r * M_o/(M_{cp} + M_{xair})$$

The value X represents the fraction of the total mass entering the flame region ($M_o + M_{xair}$) which is recirculated. In the present calculations, the value of the fraction, C_r, is assumed to be unity (in place of the value estimated above of 0.746) in light of the uncertainty involved in determining the value of this factor.

(3) The gas entrained from the gas region to the flame is assumed to be at the corresponding gas region temperature, T_{g1} or T_{g2}.

(4) The mass of recirculated gas is not effected by assumption (1), and its composition is assumed to be that of the gas exiting the flame region.

B2.0 Determination of the Gas Temperatnre in Each Section of the Flame Region

The gas in the flame region surrounding the flame of the kiln is heated simultaneously by the thermal convection (mixing) due to gas recirculation and by radiation heat transfer in the kiln from the flame and wall. The exact effect of these two factors on the gas temperature calculation depends upon whether the mixing or the radiant heat transfer is calculated first. If the radiant heat transfer to the gas is calculated before it is heated by mixing, the mixed gas would be hotter. It was assumed that the gases are first mixed resulting in a 'mixed gas' temperature which was then heated by radiant heat transfer from the flame. This order of calculation maximizes the effect of gas recirculation on the gas temperature, while the opposite order would maximize heat transfer by radiation. The temperature of each gas region is determined in three steps:

(1) The gas temperatures in each section are initially assumed.

(2) An enthalpy balance for the section calculates an HMB temperature based on the gases entering and exiting it.

(3) The HMB temperature is used in the radiation balance as an initial temperature of the gas to calculate the new gas temperature of the section.

Each of these steps is discussed separately below.

Step (1): An overall flame region heat and mass balance is used to estimate the temperature of the gas leaving the flame region, which is assumed to be at the same temperature as the gas recirculated (Section B.1 assumption 4 above). The temperature of the gas leaving the flame region is based on the overall heat balance for the flame region:

$$H_{air} + H_{gas} = H_{gas} + H_{solids} + Q_{shell}$$

where H represents the enthalpy of air, gas, or solids, and Q represents the heat lost from the flame and shell. From the exit gas temperature (T_{g3}), determined by this balance, the temperatures of the gas sections in the flame region are assumed. The initial estimates for the gas temperatures in the flame are 'best guess' approximations as discussed below.

In the present calculations, the temperature of the gas exiting the flame region was first estimated from the overall balance using an estimated solid bed temperature of 600 F and heat loss based on a shell temperature of 300 F, which resulted in an exit gas temperature from the flame region of approximately 1900 F. The first estimate of the gas temperatures in the flame region were arbitrarily calculated assuming a uniform temperature rise in section 1, 2, and 3 (by dividing the overall flame region balance temperature by 3). The initial gas temperature assumed were: T_{g1} = 600 F in the first gas section and T_{g2} = 1200 F in the second gas section, and T_{g3} = 1900 F for the gas leaving the flame region.

It may be noted that this procedure could be extended to consider more than two section in the flame region.

Step (2): A heat balance is calculated for the gas temperature (shown below in the diagram) in the section of the flame region being calculated. The balance is based on the mass, composition, and assumed temperature of each stream entering the gas section. For the calculation of the first gas section, the assumed temperature of the second gas section T_{g2} is used (in this case assumed to be 1200 F). The enthalpy difference for each of the streams entering the gas section are calculated and the 'heat and mass balance' (HMB) temperature of the gas section T_{g1} is determined by a trial and error procedure of guessing the temperature of the gas section and comparing the net enthalpy difference between the entering and exiting stream enthalpy. The correct temperature of the gas section is calculated when the net enthalpy of the entering and exiting streams are equal. This is illustrated below:

```
                   |--------------|
T_go   --------->  |              |------>  T_g1
                   |   T_g1 HMB   |
T_g1    <--------  |              |<-------  T_g2
                   |--------------|
```

$$\Delta H_{T_{go} \rightarrow T_{g1}} = - \Delta H_{T_{g2} \rightarrow T_{g1}}$$

<u>Step (3)</u>: The HMB temperature T_{g1} of the gas section is used in the radiation heat transfer section of the program as the 'initial temperature to determine the temperature profile of the first section of the flame region. The high temperature of the flame and wall results in additional heat transfer to the gas (by radiation from the flame and wall, and convection from the wall).

B3.0 <u>Flame Region Temperature Convergence Criteria</u>

The temperature profile of the first section of the kiln is calculated as described above (for the flame, solid bed, wall, and gas), and yields a new estimate of the gas temperature T_{g1} in the first section (say 800 F). The temperature profile of the second section of the flame region is calculated in a similar fashion. This procedure is summarized below:

Step (1): The HMB gas temperature of the second gas section is calculated based on the new estimated gas temperature T_{g1} = 800 F of the first section and the gas temperature exiting the flame region T_{g3} = 1900 F as calculated by an overall balance of the flame region (Step 1 above). For example let the resulting HMB temperature T_{g2} = 1400 F.

Step (2): The new HMB gas temperature of the second gas section T_{g2} = 1400 F is used as the initial gas temperature to calculate the heat transferred by radiation within the kiln. For example, let the new value of T_{g2} including radiation heat transfer be 1650 F. The trial temperature profile of the second section of the kiln includes:(1) a new gas temperature T_{g2} = 1650 F for the second section, (2) the temperature of the flame combustion gases, say T_{f2} = 2000 F, (3) the solid bed temperature which exits the flame region, say T_{s2} = 1000 F and (4) the shell heat loss in the second section, say Q_{sh} = 0.2 MM Btu/hr.

Step (3): An enthalpy balance of the gases leaving the flame region (the flame combustion gases T_{f2} = 2000 F and second gas section gases T_{g2} = 1650) is calculated to determine the combined temperature of the gases T_{g3}, say 1850 F. If the calculated temperatures equal the estimated temperatures used in the overall balance of the flame region, the flame region gas temperatures assumed are correct.

If the exit gas temperatures are not equal, a new (second) estimate of the gas temperature T_{g3} leaving the flame region can be calculated using the overall balance for the flame region with the new values for the shell heat loss in the flame region, and solid bed temperature T_{s2} = 1000 F exiting the flame region. For example say the overall balance predicted T_{g3} = 1950 F. The procedure of calculating the temperature profile of the kiln in the flame region has now come full circle, and a new (second) set of trial temperatures for the gas temperatures of the second section T_{g2} = 1650 F and third section T_{g3} = 1950 F can be used to repeat the procedure. This entire procedure is repeated until the calculated temperatures (T_{g2} and T_{g3}) are the same as the previous trial values used.

It may be noted that the program continuously calculates in a section the values of the HMB gas temperature for the 'other' gas section in the flame region and the exit gas leaving the flame region, based on the corresponding enthalpy balances. These gas temperatures may be used to indicate whether a particular set of gas temperatures are likely to result in the same exit gas temperature as calculated by the overall balance of the flame region. The mass and composition of each stream for the flame region balance remains fixed for a particular set of operating parameters and the estimated combustion gas fraction recirculated. The enthalpy difference between the second gas temperature and the first gas temperature must be constant because there is only one set of 'correct' temperatures which allows the balance of the flame region to be satisfied. Lowering the second gas temperature or raising the first section gas temperature, lowers this enthalpy difference. The temperatures of the gas and flame in the second section determines the exit gas temperature, and the heat released in each flame section is fixed. Consequently, the range of temperatures which allows the temperature profile in the flame region to be determined is restricted.

Using these observations, the user is often able to 'abort' the procedure, and choose a new set of gas temperatures which will converge more quickly. The first few iterations of this procedure may be performed rapidly by using 'loose' convergence criteria for a given section of the flame region, recognizing that the assumed temperatures used in the first few iterations are not the final values.

For instance, on the second iteration say the resulting gas temperature of the second section T_{g2} = 1800 F and the resulting flame temperature of the second section Tf_2 = 2000 F, and the calculated combined gas temperature of these two resulted in 2000 F. Then, from the overall flame region balance temperature of T_{g3} = 1950 F, one would know that the second gas temperature T_{g2} = 1650 F was too high and a lower gas temperature for the second section, say 1500 F, would be required to give the estimated overall flame region balance temperature of 1950 F. This lower gas temperature of the second section would also likely result in a lower gas temperature for the first section T_{g1} as well, say 700 F. The gas temperatures assumed include the heat transferred by both convection and radiation.

Within several complete iterations of the flame region, the gas temperature of section 1 and 2 begin to get closer to their final values. The overall balance gas temperature leaving the flame region varies less each iteration of the flame region as the solid bed and shell heat loss exiting the flame region get closer to their final values. With greater confidence in the overall balance gas temperature leaving the flame region, the gas temperatures in the flame region may be 'fine tuned' to determine the temperature profile of the flame region.

APPENDIX C

CALCULATIONS FOR MODELING THE FLAME AS A GRAY BODY IN THE FLAME RADIATION BALANCE.

C1.0 Radiation Model of the Flame

The flame is modeled as an axial flame and is treated in the radiation balance as a black body surface of a cylindrical shape. This simplification significantly reduces the equations required to trace the emitted and reflected radiation within the enclosure for constructing the radiation balance. A real flame is different from a gray solid surface because some of the radiation is transmitted through the flame. The flame is here treated as a black body of reduced area to avoid the complications otherwise involved in calculating the radiation balance of the flame treated as a partially transparent gray body. The flame is treated as an opaque black body of reduced area such that the radiation emitted or absorbed is equivalent to that of the partially transparent flame with the actual flame area. With the reduced area, less volume is occupied by the flame, which therefore intercepts less radiation in the kiln and is effectively more 'transparent'.

The mathematical relations involved in this model are given in the following. The heat emitted to the kiln wall by the flame, considered as a grey body with emissivity ε_f and area A_f, is equated to that emitted by a reduced area flame considered as a black body with emissivity ε'_f and area A'_f, i.e.,

$$Q_{f->w} = Q'_{f->w} \quad .$$

Substituting the general expression for radiation heat transfer,

$$\sigma A_f \varepsilon_f F_{fs} T_f^4 = \sigma A'_f \varepsilon'_f F'_{fs} T_f^4$$

The view factors F_{fw} and F'_{fw} are equal because of the cylindrical geometry of the kiln. Therefore,

$$A_f \varepsilon_f = A'_f \varepsilon'_f, \qquad \text{Eq. C1.0-1}$$

where ε'_f equals 1 since the reduced area flame is considered to be a black body.

Now using Kirchoff's law for the radiation between the wall and the flame for the actual area case,

$$A_w F_{wf} = A_f F_{fw} \quad .$$

For the reduced area case,

$$A_w F'_{wf} = A'_f F_{fw}$$

Eliminating F_{fw} between these equations yields

$$A_w F'_{wf} = A'_f (A_w F_{wf}/A_f) \quad .$$

Simplifying,

$$F_{wf}/F'_{wf} = A_f/A'_f$$

Therefore, using Eq C1.0-1,

$$F_{wf}/F'_{wf} = \varepsilon_f = \alpha_f \quad .$$

Therefore,

$$F_{wf} - F'_{wf} = (1-\alpha_f)F_{wf} \qquad \text{Eq. C1.0-2}$$

From this last equation and Eqns. C1.1-3 and C1.1-6, it follows that:

$$F_{wf}(1-\alpha_f) = (F'_{ws} - F_{ws}) + (F'_{ww} - F_{ww}) \qquad \text{Eq. C1.0-3}$$

This derivation shows that the fraction of energy radiated by the wall which is transmitted through the flame (treated as a gray body) is equal to the difference between the view factor F_{wf} for the gray body case and the black body view factor F'_{wf}.

Such treatment of the flame has not been discussed in the literature.

The reduced area of the black body flame causes a reduction of the operative view factors ($F'_{wf}F'_{sf}$) which determine the fraction of radiation which will be emitted by each of the two surfaces to the black body flame. This treatment compensates for the energy that would have been transmitted through the flame as if it were a gray (partially transparent) body. This treatment greatly simplifies the calculation of the radiation balance. Treating the flame as a gray body would double the number of equations required to calculate the radiation absorbed by the gas because the additional equations would be required to account for radiation which passed through the flame.

The difficulty involved in considering the flame as a gray body is that the flame is a partially transparent surface. For a partially transparent surface, part of the emitted radiation (from the solid bed or wall) which is 'viewed' by the (flame) surface is transmitted through the partially transparent (flame) body. The radiation emitted from the solid bed which is transmitted through the flame is intercepted by the wall (and partly reflected). For the radiation emitted by the wall to the flame, the radiation transmitted through the flame may be intercepted by either the solid bed or the wall. (See Fig. C1.0-1) Some reflected radiation (originally emitted from the flame, wall, solid bed, and gas) also would pass through the flame. The difficulty in accounting for the radiation transmitted through the flame is complicated further by the fact

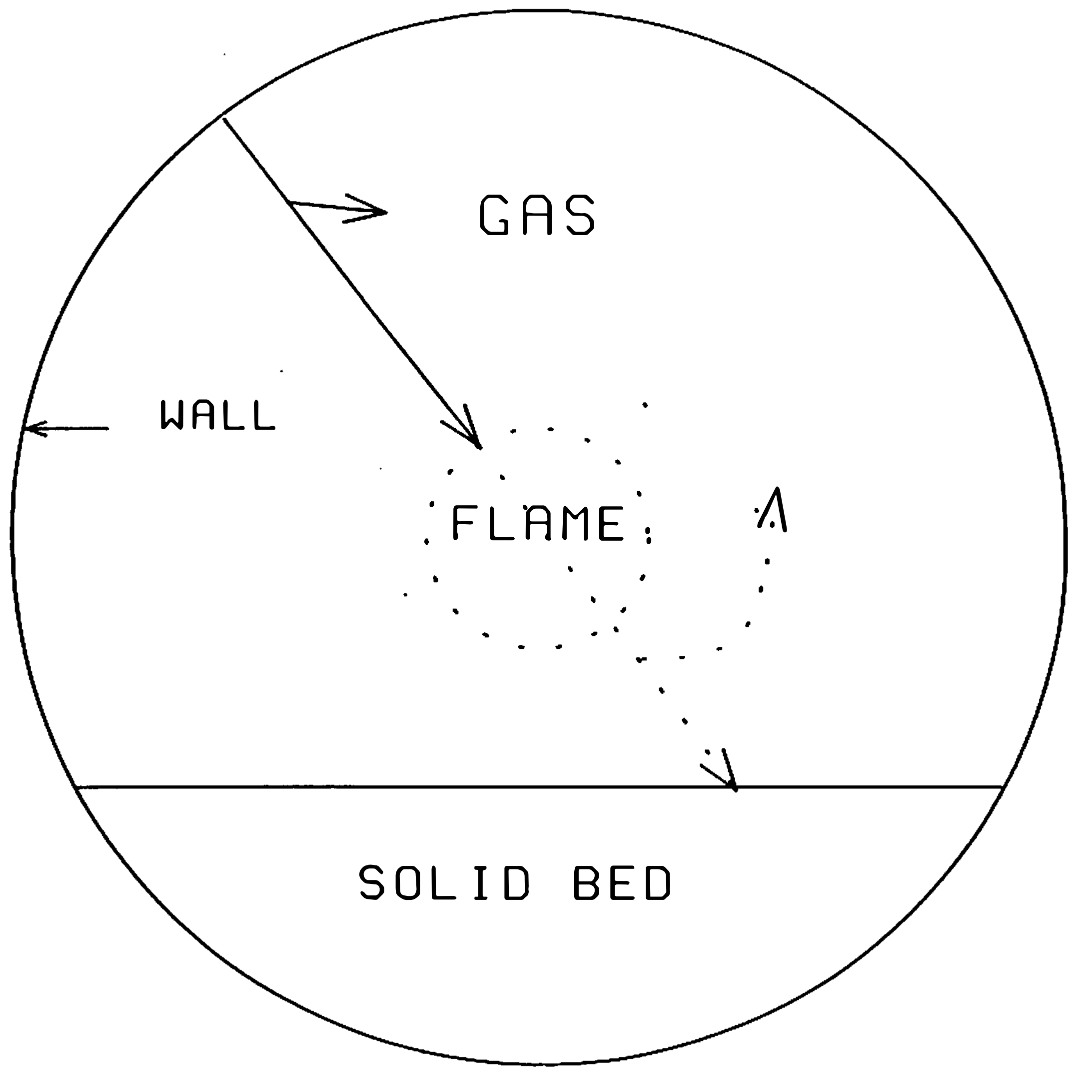


Figure C1.0-1. Radiation Transmitted Through the Flame with Gas Absorption Before and After the Flame

that the gas would also absorb some fraction of each of the radiation rays. Two gas absorption terms would be required to describe each ray which intercepts the flame, one before intercepting the flame and one after passing through the flame before the ray is intercepted by another solid surface (see Fig. C1.0-1)

C1.1 <u>Numerical Comparison of the Gray Flame and Reduced Area Flame Treatments</u> -

The calculation of the view factors and heat transfer for the gray flame method and the reduced area flame method is illustrated in the following numerical example. The following numerical values for the parameters of interest were chosen:

$\beta_s = 90^\circ = \pi/2$ radians = the angle subtended by the solid bed

$D_f = 2$ feet = the diameter of the flame (actual)

$D_k = 10$ feet = kiln ID

$\varepsilon_f = \alpha_f = 0.8$ = emissivity and absorptivity of the flame (actual or gray body)

From these numerical values, the following quantities are calculated:

$F_{fw} = F'_{fw} = (2\pi - \pi/2)/2\pi = 3/4$ = fraction of flame radiation intercepted by the wall

$F_{fs} = F'_{fs} = (\pi/2)/2\pi = 1/4$ = the fraction of flame radiation intercepted by the solid bed

$A_f = \pi\ D_f$ = area of the flame per unit length of kiln $= 6.28\ ft^2/ft$

$A_s = SIN(\beta_s/2)\ D_k = (2^{.5}/2)\ 10$

= area of solid bed per unit length of kiln = $7.07\ ft^2/ft$

$A_w = (\pi - \beta_s/2)\ D_k = (3/4)\ \pi\ 10$

$=$ area of wall per unit length of kiln $= 23.56\ ft^2/ft$

The treatment of the gray flame will be considered first and compared to the treatment of the flame as a black body of reduced area. Several mathematical relationships for these calculations need to be defined:

(1) All radiation leaving a surface i within an enclosure must be intercepted by the enclosure surfaces. This results in the following mathematical relationships between the view factors:

$$\sum_{j=1}^{N} F_{ij} = 1 \qquad \text{Eq. C1.1-1}$$

From this it follows that,

flame - $F_{fs} + F_{fw} = 1$ Eq. C1.1-2

wall - $F_{ws} + F_{ww} + F_{wf} = 1$ Eq. C1.1-3

solid bed - $F_{sw} + F_{sf} = 1$ Eq. C1.1-4

Similar equations can be written for the reduced area case:

flame - $F'_{fs} + F'_{fw} = 1$ Eq. C1.1-5

wall - $F'_{ws} + F'_{ww} + F'_{wf} = 1$ Eq. C1.1-6

solid bed - $F'_{sw} + F'_{sf} = 1$ Eq. C1.1-7

The axial radiation and end effects from the kiln end surfaces have been neglected in this treatment.

(2) Kirchoff's law is a useful relationship between the view factor from one surface to a second surface within an enclosure:

$A_i\ F_{ij} = A_j\ F_{ji}$ Eq. C1.1-8

(3) The total radiation which is intercepted by a partially transparent surface which does not reflect radiation is either absorbed or transmitted through the medium, as represented by

the following expression:

$$\tau_i + \alpha_i = 1 \qquad \text{Eq. C1.1-9}$$

<u>Determination of</u> F_{wf} and F'_{wf} -

Solving Kirchoff's law for F_{wf},

$$A_w \, F_{wf} = A_f \, F_{fw}$$

$$\begin{aligned} \text{or, } F_{wf} &= A_f \, F_{fw} \,/\, A_w \\ &= (\pi \, D_f) \, F_{fw} \,/\, (\pi - \beta_s/2) \, D_k \\ &= (2 \, \pi) \, (3/4) \,/\, (\pi - \pi/4) \, 10 \\ &= 0.20 \end{aligned}$$

Going through a similar calculation for F'_{wf},

$$A_w \, F'_{wf} = A'_f \, F_{fw}$$

$$\begin{aligned} \text{or, } F'_{wf} &= A'_f \, F_{fw} \,/\, A_w \\ &= \varepsilon_f (\pi \, D_f) \, F_{fw} \,/\, (\pi - \beta_s/2) \, D_k \\ &= (0.8)(2 \, \pi) \, (3/4) \,/\, (\pi - \pi/2) \, 10 \\ &= (0.8)(1/5) = 0.16 \; . \end{aligned}$$

The fraction of energy transmitted through the flame is given by the following formula (form Eq. C1.1-9):

$$\tau_f = 1 - \alpha_f \qquad \text{Eq. C1.1-10}$$

The fraction of radiation emitted by the wall which is transmitted through the flame (to the solid bed or wall) is given by the product of the fraction of energy transmitted through the flame times the view factor, F_{wf}:

$$F_{wf} \; (1 - \alpha_f) \qquad \text{Eq. C1.1-11}$$

which equals

$$0.20(1-.8) = 0.04$$

It is seen that this is equal to the quantity

$$F_{wf} - F'_{wf} = 0.2 - 0.16 = 0.04 \quad .$$

This equality is consistent with the relationship derived above (Eq. C1.0-2),

$$F_{wf} - F'_{wf} = F_{wf}(1-\alpha_f) \quad .$$

C2.0 <u>Evaluation of the Other View Factors</u>

The determination of the view factors involves the use of Kirchoff's law and Eq. C1.1-1,

$$\underset{j=1,n}{} F_{ij} = 1 \quad .$$

These view factors will be used in the solution of Eq. C1.1-4,

$$F_{ws} + F_{ww} + F_{wf} = 1$$

<u>Determination of</u> F_{ws} and F'_{ws} -

By Eq. C1.1-4,

$$F_{sw} = 1 - F_{sf}$$

By Kirchoff's Law, this yields,

$$\begin{aligned} F_{sw} &= 1 - A_f\ F_{fs}\ /\ A_s \\ &= 1 - (\pi\ D_f)\ F_{fs}\ /\ \mathrm{SIN}[(\beta_s/2)\ D_k] \\ &= 1 - 0.2221 = 0.7781 \end{aligned}$$

Now, the view factor F_{ws} may be determined using Kirchoff's law as follows:

$$A_w\ F_{ws} = A_s\ F_{sw}$$

and
$$\begin{aligned} F_{ws} &= A_s\ F_{sw}/A_w \\ &= [\mathrm{SIN}(\beta_s/2)\ D_k\ F_{sw}]/(\pi-\beta_s/2)\ D_k \\ &= (2^{.5}/2)(10)(0.7781)/(3/4)\pi\ 10 \end{aligned}$$

$$F_{ws} = 0.2335$$

Alternately, a direct solution can be written to solve for F_{ws} which does not include the intermediate solutions of the F_{sf} and F_{sw}:

$$F_{ws} = A_s\ F_{sw}\ /\ A_w$$
$$= A_s\ (\ 1\ -\ F_{sf})\ /\ A_w$$
$$= A_s\ (1\ -A_f\ F_{fs}\ /\ A_s)\ /\ A_w$$
$$= SIN(\beta_s/2)(1-(\pi * D_f)F_{fs}/[SIN(\beta_s/2)D_k])/(\pi-\beta_s/2)/D_k$$

<u>Determination of the View Factors</u> F'_{sw} and F'_{ws} -

By Kirchoff's law,

$$A_w\ F'_{ws} = A_s\ F'_{sw}$$

By Eq C1.1-7,

$$F'_{sw} = 1-F'_{sf}$$

By Kirchoff's Law,

$$F'_{sf} = A'_f\ F'_{fs}\ /\ A_s$$
$$= \varepsilon_f\ (\pi\ D_f)\ F'_{fs}\ /\ [SIN(\beta_s/2)\ D_k]$$
$$=(0.8)\ (2\pi)\ (1/4)\ /\ [SIN(\pi/4)\ 10]$$
$$F'_{sf} = (0.8)(0.2221) = 0.1777$$

Therefore,

$$F'_{sw} = 1\ -0.1777$$
$$= 0.8223$$

Now, the view factor F'_{ws} may be determined using Kirchoff's law as follows:

$$F'_{ws} = A_s\ F'_{sw}\ /\ A_w$$
$$F'_{ws} = SIN(\beta_s/2\ )\ F'_{sw}\ /(\pi\ -\ \beta_s/2)\ D_k])$$
$$= (2^{.5}/2)(10)(0.7781)/(3/4)\pi\ 10$$
$$F'_{ws} = 0.2468$$

or alternatively, $F'_{ws} = A_s F'_{sw} / A_w$

$$= (A_s (1-F'_{sf}))/ A_w$$

$$= [A_s (1 - A'_f F_{fs} / A_s)] / A_w$$

$$=(SIN(\beta_s/2)(1-\varepsilon_f(\pi*D_f)F_{fs}/[SIN(\beta_s/2)D_k]))/(\pi-\beta_s)$$

<u>Calculation of</u> $F'_{ws} - F_{ws}$ -

From the values of F'_{ws} and F_{ws} calculated above,

$F'_{ws}-F_{ws} = 0.2468-0.2335 = 0.0133$

As discussed above (Eq. C1.0-3), F'_{ws} minus F_{ws} is equal to the radiation emitted from the wall and transmitted through the flame to the solid bed.

<u>Determination of</u> F_{ww} and F'_{ww} -

We now have the values to determine F_{ww} from the equation,

$F_{ws} + F_{ww} + F_{wf} = 1$

and,

$F_{ww} = 1 - F_{ws} - F_{wf}$

$F_{ww} = 1 - 0.2335 - .2$

$F_{ww} = 0.5665$

Similarly, F'_{ww} is determined:

$F'_{ww} = 1 - F'_{ws} - F'_{wf}$

$F'_{ww} = 1 - 0.2468 - 4/25$

$F'_{ww} = 0.5932$

<u>Calculation of</u> $F'_{ww} - F_{ww}$ -

From the values of F'_{ws} and F_{ws} calculated above,

$F'_{ww}-F_{ww} = 0.5932-0.5665 = 0.0267$

As discussed above (Eq. C1.0-3), F'_{ww} minus F_{ww} is equal to the radiation emitted from the wall and transmitted through the flame to the solid bed.

The sum of the differences between F'_{ws} minus F_{ws} and F'_{ww} minus F_{ww} equals the difference F_{wf} minus F'wf and is consistent with Eq. C1.0-3,

$$F_{wf}(1-\alpha_f) = (F'_{ws} - F_{ws}) + (F'_{ww} - F_{ww}) \quad .$$

Appendix D

Operating Data from the ERRU Kiln

Project No.
TITLE Book No.

From Page No. 11/8/84

Test 1 Clarksburg Soil
waste oil on
water spray off
15 ~~mon~~ 16 charge 20 sec dwell
Start 935 AM
940 reduce dwell to 10 seconds - corbel look fine - No ash jams
945 ash temp 740°C 1364°F
1005 ash temp 785°C
1025 John Deere shut down - restarted
1125 ash temp 810°C
1135

Drum Cooling Data

Drum #	time removed	net wt	fullness	core Temp °C
1	935	~~232~~	1/3 (55)	685
2	955	244	1/3	730
3	10:10	313	1/2	800
4	1025	311	1/2	800
5	1055	258	1/2	795
6	1110	306	1/2	810
7	1125	349	2/3	820
8	1140	286	1/2	812
9	1150	348 ~~304T~~ less drum wts		

1208/6/12 dry

1142 changing CHEAF media tripped out ID Fan vacuum interlock

1145 informed by YSC that they ~~are~~ have not ~~mis~~ sampled last point before CHEAF upset.
We decided that we would conclude test without last point since it is a very low velocity zone and would not ~~great~~ significantly effect results

To Page No.

Signature | Date | Invented by | Date
Recorded by

Project No. ______
12 Book No. ____ TITLE ______

From Page No

Soil Moisture

Missouri Soil in Bag 17% H_2O
Dry " " on ground 13.7% "

Clarksburg soil 10.1% H_2O
Dry " " 5.7% H_2O

210 Test 2 start
20 lb charge 10 sec dwell 1.07 KPM

243 1 min 23 sec per RAM cycle
303 1 min 7 sec per RAM cycle

255 ash temp 722°

4PM hooked up 4-20 ma output from solids feed to Gulton recorder in monitoring trailer

415 ash temp 740°C
418 Test 2 completed

drum wts

time	net wt
230	~~281~~ 278
250	~~270~~ 267
310	~~286~~ 283
330	~~192~~ 190
350	~~286~~ 283
410	~~353~~ 350
420	~~215~~ 203
Mixed	208

To Page No.

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by	

Project No.

Book No. 13

Page No.

6 PM Test 3 Start Montmorillonite
20 lb/chg 10 sec dwell
40 sec cycle BAM

7:04 pm Ash temp drum 6:51 pm 738 °C

There is no indication of dusting as the ash falls out into the ash drum. Material comes out red and quickly cools on surface.

7^{42}_{pm} Ash T = 735 °C Drum 7^{35}_{pm}

Drum weights

	time	net wt
Start	6:25	255
	6:38	210
	6:51	224
	7:02	231
	7:13	214
	[illegible]	227
	7:35	212
	7:45	227
	7:54	208

Test 3 complete 8:15 pm 11/8/84

8:00	210
8:11	196
8:17	153

To Page No.

Read & Understood by me.	Date	Invented by	Date

14 Project No. ____ Book No. ____ TITLE ____

From Page No

$$\frac{56\,gal}{drum} \cdot \frac{ft^3}{7.48\,gal} \times 62\frac{lb}{ft^3} = 456\ lb/drum$$

10% H_2O
46 lb
add 5 gal to get 18% loading

11/9/84 @ 1:10 pm
Test # 4 Wet Clarksburg Soil @ 5 gal H_2O added to each drum ~ 18% moisture

Initial conditions
~ 2000 lbs/hr.
SCFM kiln Air = 1050
WO : 126 lbs/hr
FO : 4 gal/min
kiln T = 1850
% O_2 = 7.5

Time	°C Solids Temp	°F Kiln T	Air SCFM	Waste oil lbs/hr	O_2 %	net drum wt
1:35 pm	775	1850	1050	126	7.57	377.5
problem with solids feed control - reach high point and ram feeds nothing for ~10 min						
2:07 pm	725	1830	1000	112	7.82	355.5
2:40 PM	717	1800	1050	111.7	7.70	~~405.0~~ 371.8
2:58 PM	760	1800	1050	111.7	7.46	405
3:15 p	750	1790	1050	110.6	7.98	378.5
3:30	750					~~368~~
4:2						

To Page No. ___

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

TITLE Book No.

From Page No.

11/9/84 Dry Clarksburg Soil

355	ash ~~temp~~	750°C	454
410	ash temp	770°C	463
430	ash temp	790°C	426
445	ash temp	770°C	498
500	ash temp	710 °C	460

To Page N

...stood by me	Date	Invented by	Date
		Recorded by	

ROTARY KILN AND SCC OPERATING LOG SHEET

DATE: 11/8/84 SHIFT: DAY OPERATOR: CT/[illegible]

ITEM	TAG #	UNITS	TIME 9:00AM	10:00A	11:00A	12:00N	1:00P	2:00P	3:00P	4:00P	5:00P	6:00P	7:00P	[illegible]
Kiln Temperature	TIC-101	°F	1840	1850	1840	1840	1820	1850	1840	1820	1800	1800	1830	1800
Kiln Comb Air Flow	FI-102	SCFM	1200	1250	1250	1200	1200	1250	1250	1250	1300	1300	1300	1250
SCC Temperature	TIC-201	°F	2090	2080	2160	2100	2140	2165	2160	2150	2170	2160	2170	2150
Waste Solids Flow Rate		LBS/CHG	10	15	15	15	—	20	20	20	[illegible]	—	20	20
Ambient Temperature		°F	45	49	51	52	50	58	56	55	5[illegible]	45	43	43
Kiln Comb Air Temp		°F	70	72	74	75	75	77	80	80	80	76	74	74
Kiln Water Flow	FI-106	GPM	—	—	—	—	—	—	—	—	—	—	—	—
Kiln Blower Pressure		in H2O	31.5	31	30.5	30.5	31	30.5	30.5	31	32	32	31.5	32
Waste Oil Flow Rate	FI-150	LBS/HR	152.6	147.4	136.4	163.5	—	107.9	133.4	146	[illegible]	125	139.8	157.6
Burner 2 Fuel Flow	FI-104B	GPH	3.5	4	4	4	15	4	4	4	4	4	4	4
Burner 4 Fuel Flow	FI-204B	GPH	25	25	24	24	23	23.5	24	24	[illegible]	23	24	24
Total SCC Gas Flow	FI-202	in. H2O	0.15	0.07	0.20	—	—	—	0.57	—	[illegible]	0.60	0.63	—
Burner 1 Fuel Flow	FI-104A	GPH	—	—	—	—	15	—	—	—		—	—	—
Water Atom Pressure	PI-112	PSI	25	24.5	24	25	[illegible]	26	26	25	[illegible]	25	25	25
Waste Oil Atom Press		PSI	25	25	24	25	25	26	25	25	[illegible]	22	25	25
Kiln Vacuum		in H2O	1.1	1.2	1.1	1.0	0.5	1.3	1.4	1.3	[illegible]	1.5	1.5	1.7
SCC Vacuum		in H2O	2.5	2.0	1.5	1.5	0.5	1.6	1.8	1.3	[illegible]	2.6	2.0	2.3
SCC Blower Pressure		in H2O	25.5	25.5	25	24.5	24	25	25	25	25	[illegible]	25.5	25
Burner 3 Fuel Flow	FI-201A	GPH	25	24.5	24	24	23	24	23.5	24	[illegible]	24	24	24
SCC Comb Air Temp	TI-203	°F	68	69	74	74	76	78	77	76	74	73	75	74
SCC Comb Air Flow	FI-201	SCFM	1250	1200	1200	1250	1200	1200	1200	1200	[illegible]	1200	1250	1250
Kiln Drive Flow		GPM	3.2	3.2	3.2	3.2	3.2	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Operator Comments: Test #1 Clarksburg Soil Start @ 9:35 AM. Increased Kiln drive to 5 gpm @ 2:00 to increase rpm

Test #2 Missouri Clay @ 2:10 pm

Test #3 Kat Litter @ 6:06 pm

TEST ENDED @ 8:10 pm

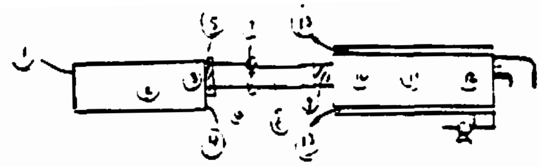
TABLE 7 AIR POLLUTION CONTROL EQUIPMENT OPERATING LOG SHEET

HOURLY LOG

DATE: 11/8/84 SHIFT: DAY OPERATOR: CT/MP/ZB

ITEM	TAG #	UNITS	TIME											
			9:00AM	10:00	11:00	12:00P	1:00P	2:00P	3:00P	4:00P	5:00P	6:00P	7:00P	8:00P
Quench Water Temp.	TI-335	°F	170	171	170	170	172	171	171	172	170	170	170	170
Quench H20 Press DNST	PI-335	PSI	46	40	4[illegible]	41	45	40	46	40	46	40	46	46
Quench Recycle Flow	FI-335	GPM	52	48	50	45	50	44	51	47	46	44	51	51
Quenched Gas Temp.	TSH-336	°F	210	210	210	215	215	215	215	215	215	210	215	220
CHEAF Exit Temp.		°F	170	170	170	168	170	171	170	168	168	170	170	120
CHEAF Water Flow	FI-355	GPM	14	14	14	14	14	14	14	14	14	15	15	15
CHEAF Water Temp.	TI-355	°F	130	129	130	129	132	130	131	131	130	131	132	130
CHEAF Filter Differ	DPI-356	in H20	25	23.6	23.5	24	24	25	24	23.6	23.5	23	24.5	23
CHEAF Outlet Press	PI-358	in H20	30	28	27.5	28.5	27.5	28	28.5	28	28	27	29	27
CHEAF Inlet Press	PI-357	in H20	5.5	4.6	4.5	4	3.6	4.0	4.5	4	4.5	4.5	3	4.5
CHEAF H20 Press DNST		PSI	24.5	21	24	25	25	25	25.5	25.5	25	25	24.5	25
Scrubber Water Temp.	TI-375	°F	160	162	16[illegible]	162	163	161	162	163	161	162	161	161
Scrubber Water Press	PI-375	PSI	22	21.5	2[illegible]	22	22.5	23	22	22.5	22.5	22.5	23	23
Scrubber Water Flow	FI-375	GPM	145	146	150	146	142	145	140	142	140	140	138	130
ID Fan Inlet Press	PI-376	in H20	31.5	31	31	31.5	30.5	30.5	31	32	31	30	32	[illegible]
Quench Water pH	PHIC-335		7.8	7.5	7.[illegible]	7.4	7.6	7.5	7.5	7.5	7.4	5.8	7.8	8
CHEAF Water pH	PHIC-354		7.8	7.9	9.[illegible]	8.5	7.5	[illegible]	8.9	8.0	8.1	8.0	8.0	6
Scrubber Water pH	PHIC-374		8.7	8.7	8.[illegible]	8.7	8.6	8.6	8.7	8.6	8.8	8.8	8.6	8.5
ID Fan Vibration		mil	0.7	0.7	0.8	0.8	0.9	1.0	1.0	0.9	0.8	0.6	0.8	0.7
Stack Temperature	TI-376	°F	176	171	17[illegible]	178	174	170	168	172	168	172	178	175
ID Fan Drive Speed		RPM	1850	1760	[illegible]	1750	1750	1700	1725	1750	1750	1800	1800	1800
Makeup Water Press	PI-304	PSI	30	30	3[illegible]	30	30	30	29	29	29	28	29	28
Makeup Water Flow	FCV-372	GPM	11	10	1[illegible]	10	10	10	10	10	10	18	10	10

COMMENTS:



5 JJC 5-10-[illegible]

<u>Radiation Losses</u>

I System Surface Temps & Ambient Parameters

Test	1	2	3	4
Date	3/31	4/1	4/1	4/1
Time	6-8AM	5-8AM	1-3pm	8-10pm
Ambient Temp				
Relative humidity				
Grw./lb DG.				
RK/SCC Temp (°F)	1644/2070	1643/2113	1680/2147	1680/2153
Estimated Rotary Kiln Surf Temp (°F)				
1	875	875	900	900
2	340	340	350	350
3	340	340	350	350
4	730	730	760	760
Duct RC/SCC				
5 'assumption'	1640	1643	1680	1680
7 (assumed temp)	1600	[illegible]	1690	1640
9 (assumed Temp)	1600	1600	1680	1640
6	?	?	?	?
8	?	?	?	?
SCC				
10				
11				
12				
Cooling Air T. 13				
Cooling Air Flow 13				

Erra Data

D = 52"
L = 16'
shell, in = 44
ins1 = 4   KK1 = 4.0
ins2 = 2   KK2 = 2.0

9:35 Am 11/3 from 2-6 - clarks burg soil 1200 $\#$/hr DRY @ 10.6% wt
from 2-7 missouri clay   @ 4% loading
2-8   @ 7% Loading

2-6 T_g = 1004°C (1840°F)
firing rate ~ 3.4 mm Btu/hr

2-7 1025 lb/hr Dry 17% wet heat = 3.1 mm Btu/hr

before 11/8 Ca[illegible] 30 ρ75 6"

11/8 Jade Park 88-P 4" ρ55 E_g" = 1.5-2.0
k = 4.5 / 3.0
1.5 | 1800F / 2
7/8 shell

C_p soil = ? .26

2" insulating fire IFB   Green lite #30
E_g" - 3.0   k = 2.0 BTU overall   BTU in/ft² °F hr
1000°F

Appendix E

Program Listing for Direct Fired Kiln

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q

1 PRIMARY BURNER AND CHAMBER MASS AND HEAT BALANCE RESULTS

Row		(1) TOTAL WASTE + FUEL LB/HR	LB-M/HR	(2) AUX FUEL TO BURNER LB/HR	LB-M/HR	(3) WASTE TO BURNER LB/HR	LB-M/HR	(4) WASTE TO CHAMBER LB/HR	LB-M/HR	(5) PYROLSIS PRODUCTS LB/HR	LB-M/HR
7	C	155 23	12.94	155 23	12 94	0 00	0 00	0 00	0 00	0 00	0 00
8	H2	22.46	11 23	22 46	11 23	0 00	0 00	0 00	0 00	0 00	0 00
9	O2	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
10	N2	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00
11	WATER	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
12	CI	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00
13	S	0.30	0 01	0 30	0 01	0 00	0 00	0 00	0 00	0 00	0 00
14	BR	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00
15	F	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
16	SALT	0 00	----	0.00	----	0 00	----	0 00	----	0 00	----
17	ASH	0 00	----	0 00	----	0.00	----	0.00	----	0.00	----
18		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
19	TOTAL	178 00	24 18	178 00	24 18	0 00	0 00	0 00	0 00	0 00	0.00
21	SCFM									0	
22	ACFM									0	
23	TEMP F	ERR		60		ERR		ERR		2353	
24	ENTHALPY	0 000		0 000		0 000		0 000		0.000	
25	HEAT REL	3.415		3 415		0 000		0 000		0.000	
26		--------		--------		--------		--------		--------	
27	MM BTU/HR	3.415		3.415		0 000		0 000		0 000	

Row			WASTE	AUX FUEL	IN AIR	TOTAL
29	PRIMARY CHAMBER					
30	HEAT BALANCE		WASTE	AUX FUEL	AIR	TOTAL
31		MM BTU/HR	0.000	3 415	0 037	3.452

32 HMB PROGRAM FOR PRIMARY AND SECONDARY COMBUSTION SYSTEMS INCL PYROLYSIS

33 FILE: HMB.WKS by: D. M. PITIS

34 INPUT TEMPLATE 1 PRIMARY CHAMBER WASTE DATA

Row		PRIMARY	BURNER WASTES			CHAMBER WASTES		
36	NAME:	AUX FUEL	WASTE 1	WASTE 2	WASTE3	WASTE 4	WASTE 5	WASTE 6
37	% C	87.21	0.00	0.00	0.00	0.00	0 00	0.00
38	% H2	12.62	0.00	0.00	0.00	0.00	0 00	0 00
39	% O2	0.00	0.00	0.00	0 00	0.00	0.00	0.00
40	% N2	0.00	0 00	0 00	0 00	0.00	0 00	0 00
41	% WATER	0 00	0.00	0.00	0.00	0 00	0 00	0.00
42	% CL	0.00	0.00	0 00	0.00	0.00	0 00	0 00
43	% S	0. 17	0.00	0.00	0 00	0.00	0 00	0 00
44	% BR	0.00	0.00	0.00	0.00	0 00	0.00	0.00
45	% F	0.00	0.00	0.00	0.00	0.00	0.00	0 00
46	% SALT	0.00	0.00	0.00	0.00	0.00	0.00	0 00
47	% ASH	0 00	0.00	0.00	0 00	0.00	0.00	0 00
48		--------	--------	--------	--------	--------	--------	--------
49	TOTAL	100.00	0.00	0.00	0.00	0 00	0 00	0 00
50	LB/HR	----	0 00	0.00	0 00	0 00	0 00	0 00
51	BTU/LB	19188	0	0	0	0	0	0
52	TEMP F	60	60	60	60	60	60	60
53	BTU/LB F	0 50	0 50	0 50	0 50	0 50	0 50	0 50

TEMPLATE 2 PRIMARY BURNER AND CHAMBER COMBUSTION CONDITIONS/CALCULATION

Row				
35	% EXCESS AIR FOR FUELS TO BURNER	========>	10.00	
36	% EXCESS AIR FOR WASTES TO CHAMBER	========>	0 00	
37	RADIATION LOSS (MM BTU/HR)	========>	1 17	<==QI orQg
38	AIR TEMP F	========>	69 92	
39	AIR HUMIDITY (LB/LB DRY AIR)	========>	0 01	
40	% ASH IN EXIT	========>	0.00	
41	% SALT IN EXIT	========>	0.00	
43	PYROLYSIS (1 = YES, 0 = NO)	========>	0	
44	HEAT OF PYROLYSIS BTU/LB	========>	360.00	
45	AVG MOL WEIGHT OF PYROLYSIS PRODUCTS	========>	50.00	
46	% FIXED CARBON IN ASH	========>	0.00	
47	SPECIFIC HEAT OF ASH (BTU/LB F)	========>	0 26	
48	DESIRED ASH DISCHARGE TEMPERATURE F	========>	0.00	<- USED IF INPUT
50	DESIRED OR "GUESS" TEMPERATURE F	========>	2352 50	<==!!
51	LBS/HR AUX FUEL	========>	178.00	521 16
52	HEAT IN = 3 452 HEAT OUT =	3 452		* DELTA H = 0 00028

55 PAUX LB/HR = 178 00 % FUEL COMB SECT 1 = 100% 29-Feb XMD = 0.00

	(6) SOLIDS OUT BOTTOM LB/HR	LB-M/HR		(7) TOTAL AIR LB/HR	LB-M/HR	(8) AIR TO BURNER LB/HR	LB-M/HR	(9) AIR TO CHAMBER LB/HR	LB-M/HR	(10) COMBUSTION PRODUCT LB/HR	LB-M/HR	(11) TOTAL OFF-GAS LB/HR	LB-M/HR
	0.00	0.00	CO2	0.00	0.00	0.00	0.00	0.00	0.00	569.19	12.94	569.19	12.94
	0.00	0.00	PYRO GAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	O2	653.37	20.42	653.37	20.42	0.00	0.00	59.40	1.86	59.40	1.86
	0.00	0.00	N2	2163.23	77.26	2163.23	77.26	0.00	0.00	2163.23	77.26	2163.23	77.26
	0.00	0.00	WATER	28.17	1.56	28.17	1.56	0.00	0.00	230.34	12.80	230.34	12.80
	0.00	0.00	HCL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.01	0.61	0.01
	0.00	0.00	HBR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	HF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	----	SALT	----	----	----	----	----	----	0.00	----	0.00	----
	0.00	----	ASH	----	----	----	----	----	----	0.00	----	0.00	----
	0.00	0.00	TOTAL	2844.76	99.24	2844.76	99.24	0.00	0.00	3022.76	104.86	3022.76	104.86
			SCFM	628		628		0		663		663	
			ACFM	640		640		0		3588		3588	
	2353		TEMP F	70		70		70		2353		2353	
	0.000		ENTHALPY	0.037		0.037		0.000		2.283		2.283	
	0.000		HEAT REL	0.000		0.000		0.000		0.000		0.000	
	0.000		MM BTU/HR	0.037		0.037		0.000		2.283		2.283	

OUT

OFF-GAS	ASH	HEAT OF PYROLYSIS	HEAT LOSS	TOTAL	HEAT IN - HEAT OUT
2.283	0.000	0.000	1.169	3.452	0.000

TEMPLATE 8 COMPONENT HEAT BALANCE BTU/HR

A	B	C		(5) PYROLYS PRODUCTS	(7) TOTAL AIR	(8) AIR TO BURNER	(9) AIR TO CHAMBER	(10) COMBUST PRODUCTS	(11) TOTAL OFF GAS
0.20	0.00	-0.00	CO2	0	0	0	0	367424	367424
0.44	0.00	-0.00	PYRO GAS	0	0	0	0	0	0
0.24	0.00	-0.00	O2	0	1546	1546	0	36317	36317
0.24	0.00	-0.00	N2	0	5252	5252	0	1353674	1353674
0.44	0.00	-0.00	WATER	0	29979	29979	0	525473	525473
0.19	0.00	-0.00	HCL	0	0	0	0	0	0
0.15	0.00	-0.00	SO2	0	0	0	0	302	302
0.08	0.00	-0.00	HBR	0	0	0	0	0	0
0.35	0.00	0.00	HF	0	0	0	0	0	0
			SALT	INCL	0	0	0	0	0
			ASH	INCL	0	0	0	0	0
			TOTAL	0	36778	36778	0	2283190	2283190
						1064			

PRIMARY COMBUSTION CHAMBER S

TEMP = 2353 F

		LBS/HR IN	LBS/HR OUT	MM BTU/HR IN	MM BTU/HR OUT
	AUX FUEL	178.00	----	3.415	----
	WASTE TO BURNER	0.00	----	0.000	----
646	WASTE TO CHAMBER	0.00	----	0.000	----
0	STOIC AIR TO BURNER	2560.54	----	0.006	----
611	XS AIR TO BURNER	256.05	----	0.001	----
626	STOIC AIR TO CHAMBER	0.00	----	0.000	----
2281	XS AIR TO CHAMBER	0.00	----	0.000	----
0	AIR HUMIDITY	28.17	----	0.030	----
498	PYRO PRODUCTS	0.00	0.00	0.000	0.000
0	COMBUSTION GAS	0.00	3022.76	0.000	2.283
0	SOLIDS OUT BOTTOM	0.00	0.00	0.000	0.000
0	HEAT OF PYROLYSIS	----	----	----	0.000
0	HEAT LOSS	----	----	----	1.169
	TOTAL	3022.76	3022.76	3.452	3.452

AIR SCFM: BURNER = 627.80 CHAMBER = 0.00 OVERALL = 627.80

% XS AIROVERALL = 10.00% OFF-GAS ACFM = 3588

```
        AL        AM        AN        AO       AP     AQ        AR        AS     AT       AU        AV       AW        AX        AY        AZ        BA        BB        BC        BD
-- -----------------------------------------------------------------------------------------------------------------------------------------------------------------------------
 1 Tg   R =   1641 97  PL(1) =     0 31 EmG =    0 232 EmG2 =    0 273 EmG3 =  0 310                 CsoG =    0 0345         EmG CSO             PL CSO
 2 Ts   R =   1837 60  PL(2) =     0 63 ABGS1 =  0 216 ABGI1 =   0 093 ABHS1   0 126 ABCS1 =   0 097 Csol =    0 0345     a =  0 01216     a =  0 01216
 3 Tm   R =   2587 64  PL(3) =     0 94 ABGW1 =  0 148 ABGI2 =   0 102 ABHS2   0 165 ABCS2 =   0 108 Cso2 =    0 0512     b =  0.06599     b =  0 06599
 4      Tf =  2811 90                   ABGS2 =  0.259 ABGI3 =   0 111 ABHS3   0 200 ABCS3 =   0 117 Cso3 =    0 0623     c = -0 01934     c = -0.01934
 5 PLC1. Tf     0 191  PL11 =   0 052                  ABGW2 =   0 198 ABHW1   0 089 ABCW1 =   0 065                   0 3811    0 0345   0 3811    0.0345 PL1
 6 PLC2. Tf     0 381  PL12 =   0 105                  ABGS3 =   0 298 ABHW2   0 128 ABCW2 =   0.081                   0 7621    0 0512   0.7621    0.0512 PL2
 7 PLC3. Tf     0.572  PL13 =   0.157                  ABGW3 =   0.238 ABHW3   0.162 ABCW3 =   0.092                   1.1432    0.0623   1.1432    0.0623 PL3
 8 --------- -------- -------   0.000  -------- ----- -------- -------- ----- --------                                                                                    |
 9 /c^(Up)^/Iccech2ob^(Up)/c^   0 000                                                                                                                                     |
10 /c^(Up)^/Iccecco2^(Up)/c^(   0.000                                                                                                                                     |
11    H2OS1   500.00 1000.00  1500 00  2000.00 ****** 3000.00  3500.00 ******  750.00                                                                                    |
12 --------- -------- ------- -------- -------- ----- -------- -------- ----- --------                                                                                    |
13 a              0.19    0.14     0 11     0.08  0.06     0.04     0 03  0 02    0 15                                                                                    |
14 b              0.14    0.14     0 14     0 13  0 12     0 10     0 08  0 07    0 15                                                                                    |
15 c             -0.01   -0.02    -0.01    -0.01 -0.01    -0.01    -0 01 -0 01   -0.02                                                                                    |
16               V=Emg     X=T                                                                                                                                            |
17        L=      0.35           Y=Emg      X=T   X^2      X^3      X^4     XY    X^2Y        N     A =      0 00       X=T  Y calc Y act=Eg                               |
18   500 00       0 24  500.00     0 24   500 00 *****************************60177 96     1 00     B =     -0.00    500 00     0 23      0.24                               |
19   750 00       0 20  750.00     0 20   750 00 *************************************     1.00     C =   4400 00   1000 00     0 19      0 18                               |
20  1000 00       0 18 1000 00     0 18  1000 00 *************************************     1 00     D =      0 24   1500 00     0 15      0 16                               |
21  1500 00       0 16 1500 00     0 16  1500 00 *************************************     1 00     E = *********  2000 00     0 12      0 13                               |
22  2000 00       0 13 2000.00     0 13  2000 00 *************************************     1 00                    2500 00     0 10      0.10                               |
23  2500.00       0 10 2500 00     0 10  2500 00 *************************************     1.00     a =      0 28   3000 00     0 08      0.08                               |
24  3000 00       0.08 3000 00     0 08  3000 00 *************************************     1 00     b =     -0.00   3500 00     0 06      0 06                               |
25  3500.00       0 06 3500.00     0 06  3500 00 *************************************     1 00     c =      0 00   4000 00     0 05      0 05                               |
26  4000.00       0.05 4000.00     0.05  4000 00 *************************************     1.00                    1837 60     0 13                                         |
27          --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                                                                           |
28            500.00              1 19 18750.00 *************************************     9.00         ABGS1 = (ABCO2+ABH2O)(1-CSO1)                                      |
29                                   Y        X   X#2      X#3      X#4     XY    X#2Y        N                       0 22                                                |
30                                                                                                     ABCO2 = ( EmCO2 @ Ts. P*L*Ts/Tg )*(Tg/Ts).65                       |
31                                                                                                                    0.10                                                |
32   CO2S1    500.00 1000.00  1500.00  2000.00 ****** 3000.00  3500.00 ******                          ABH2O = ( EmH2O @ Ts. P*L*Ts/Tg )*(Tg/Ts).45                       |
33 --------- -------- ------- -------- -------- ----- -------- -------- ----- --------                                0 13                                                |
34 a              0.11    0.09     0.10     0.09  0 08     0.06     0.05  0.04                                                                                            |
35 b              0 04    0.05     0.05     0.06  0.06     0.06     0.05  0.04                 Tg =      1641 97 PL1*Ts/Tg     0.35                                       |
36 c             -0.00   -0.01    -0.01    -0.01 -0.01    -0.01    -0.00 -0.00                 Ts =      1837.60 Csol =        0.03                                       |
37                                                                                                                                                                        |
38               Y=Emg     X=T                                                                                                                                            |
39        L=      0 21           Y=Emg      X=T   X^2      X^3      X^4     XY    X^2Y        N     A =      0.00     A =      0.00      X=T  Y calc Y act=Eg               |
40   500.00       0.12  500.00     0.12   500.00 **********************60.51 30253.61     1.00     B =     -0.00     B =     -0 00   500.00     0.12      0.12               |
41  1000 00       0.10 1000.00     0 10  1000 00 **********************95.34 95343.59     1.00     C =   2500.00     C =   6500.00  1000.00     0 10      0.10               |
42  1500 00       0.11 1500.00     0.11  1500.00 *************************************     1.00     D =      0.12     D =      0.16  1500.00     0.10      0.11               |
43  2000.00       0 11 2000.00     0.11  2000 00 *************************************     1.00     E = *********     E = *********  2000.00     0 11      0.11               |
44          --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                                      2500.00     0 09      0.09               |
45            500.00              0.43  5000.00 *************************************     4.00     a =      0 15     a =      0.21  3000.00     0 07      0.07               |
46                                   Y        X   X#2      X#3      X#4     XY    X#2Y        N     b =     -0 00     b =     -0.00  3500 00     0 06      0 06               |
47                                                                                                  c =      0.00     c =      0.00  4000 00     0.05      0.05               |
48        L=      0.21           Y=Emg      X=T   X^2      X^3      X^4     XY    X^2Y        N                                     1837.60     0.10                          |
49  2500 00       0 09 2500.00     0.09  2500.00 *************************************     1 00                                                                            |
50  3000 00       0 07 3000.00     0 07  3000 00 *************************************     1.00                                                                            |
51  3500 00       0.06 3500.00     0 06  3500.00 *************************************     1 00                                                                            |
52  4000 00       0 05 4000.00     0.05  4000 00 *************************************     1.00                                                                            |
53          --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                                                                           |
54            500 00              0 27 13000 00 *************************************     4 00                                                                            |
55                                   Y        X   X#2      X#3      X#4     XY    X#2Y        N                                                                           |
```

```
            A          B           C          D          E          F          G          H          I          J
-- -------------------------------------------------------------------------------------------------------------------
56     HEAT IN =    3.452  HEAT OUT =                 3.452             DELTA H =  0.00028                        |
57 ---------------------------------                  TI. F      Tg F     DEL Tg  BTU---------                   |
58                    T F         T. K     T NEW     2351.9       69.9          0                 0.80            |
59             Tl=   2351.9     1562.2   1562.17     2351.9     1182.0    563.560      Al  =      2.45            |
60             Tg=   1182.0      912.2    912.20      1.927     1927.5             b  AS  =     0.8269            |
61             Tw=   2127.6     1437.6   1437.58      XMO =       0.00 |              Aw  =     3.1434            |
62             Ts=   1377.6     1020.9     1.021 Fsw =         0.34176 |              Ag  =     6.4198            |
63           Tsh=     353.4      451.9           Fws =         0.08990    0.00000 ws. m =     0.8485            |
64 Tsh check =                  451.89 |         Fww =         0.30404    0.00000   Al  =       3.06            |
65       350.00        449             |            Flw =      0.77778 |           Area3 =   4.97481            |
66 Qs + Qw + Qg + Ql =          14.929    50.967    Fls =      0.22222 |           Ash  =    5.09146            |
67 Qs =   ----------------    (162.280)|            Fsl =      0.65824 |                                          |
68 Qw =   ----------------        (39)*             Fwl =      0.60606 |           rr1  m =  0.66000            |
69 Qg =   ----------------   (165.074)(563.561)ps =               0.20 |           rr2. m =  0.76160            |
70         Ql =  ---------     342.322 |         pw =             0.20 |           rr3. m =  0.81240            |
71 Qwcd =                       14.928 |         pg =             0.00 |           rsh  m =  0.83145            |
72  DEL Ts. K =    731.91       1020.91 *        ABs =            0.80 |            rl  m =  0.50000            |
73  DEL Tg. K =       ERR          ERR *         ABw =            0.80 |                                          |
74  DEL Tg. F =       ERR          ERR |            ABl =         1.00 |           D  m =       1.32            |
75 TRgs1 =                      0.7840 |         Emsh =            0.7 |           L  m =       4.87            |
76 TRgs2 =                      0.7414 |         Ems =            0.80 |           LL  m =      0.97            |
77 TRgs3 =                      0.7022 |         Emw =            0.80 |                                          |
78 TRgm1 =                      0.8517 |            Eml =         1.00 |           Thi =       80.00            |
79 TRgm2 =                      0.8025 |         Es =           61.588 |           Thrad =   1.39626            |
80 TRgm3 =                      0.7624 |         Em =          242.162 |           0.95*BQ28*(1-BQ29)             |
81                                     |         Eg =           39.260 |           F/D =       0.117            |
82 Emg =                        0.2321 |            El =       337.671 |                                          |
83 TRg11=(ABG2+A       ERR      0.1870 |         sigma =      0.000000 |           ins1. in      4.0            |
84 ABG11 =                      0.8130 |         moles total       105 |           ins2  in      2.0            |
85                                     |         Pco2 =        0.07544 |           shell. in     0.8            |
86        TRg11 =               0.9072 |         PH2O =        0.12375 |           kk1. BTU/     5.5            |
87        TRg12 =               0.8984 |         PCO2 + PH2O   0.19919 |           kk2. BTU/     2.0            |
88        TRg13 =               0.8895 |                               |           kw1. w/m* 0.79251            |
89                                     |         Lm=.66*D*(1-FD)       |           kw2. w/m* 0.28818            |
90        TRgg1 =               0.7679 |           Lm. m =        0.77 |                                          |
91        TRgg2 =               0.7274 |         2Lm .m =      1.53858 (PH2O+Pco2)*(rr1-rl) =              0.032
92        TRgg3 =               0.6897 |         3Lm .m =      2.30787 (PH2O+Pco2)*(rr1-rl)*2 =            0.064
93 ABG1 = 1 - TRgg1             0.2321 |                               (PH2O+Pco2)*(rr1-rl)*3 =            0.096
94 ABG2 = TRgg1 - TRgg2 =       0.0405 |         hcdwsh =    1/[(2*@PI*rr3)*[(rr2-rr1)/(@PI*kw1*(rr1+rr2))+(rr3-rr2)/(@PI*
95 ABG3 = TRgg2 - TRgg3 =       0.0377 |                 =     3.04423 |                                          |
96 ************************************|         hrsha =     sigma*Emsh*(Tsh*Tsh*Tsh*Tsh-Ta*Ta*Ta*Ta)/(Tsh-Ta)
97 % excess air =                10.00 |                 =     8.61594 |                                          |
98           Ta =         71       294 |         Tsh check =(hcdwsh*Area3*Tw+Ash*hcvsha*Ta+Ash*hrsha*Ta)/(hcdwsh*Area3+As
99 hcvws =                          50 |                           452 |                                          |
100 hcvgs =                         50 |         Qwcd = Qshcv + Qshr                                              |
101 hcvgw =                         20 |         Qwcd =      Area3*hcdwsh*(Tw-Tsh)                                |
102 hcvsha =                        10 |                         14928 |                                          |
103 hrsha =                          9 |         Qshcv =     Ash*hcvsha*(Tsh-Ta)                                  |
104                                    |                          8019 |                                          |
105 (PH2O+Pco2)*Lm =            0.1532 |         Qshr =      Ash*hrsha*(Tsh-Ta)                                   |
106 (PH2O+Pco2)*Lm2 =            0.306 |                          6909 |                                          |
107 (PH2O+Pco2)*Lm3 =            0.460 |         Qshcv+Qshr      14928 |                                          |
108 -------------------------------------------------------------------------------------------------------------
109 ---------------------------------  29-Feb -----------------------------------------------------------------
110 Qss+Qsw+Qsg+Qsl =             (0)    Ems =        0.80                   all 1                               |
```

```
       K                    L            M          N          O          P          Q
---------------------------------------------------------------------------------------
                                    --------   --------   --------   --------   -------
H2Og1                                 500.00    1000.00    1500.00    2000.00   2500.00
--------------------             --------   --------   --------   --------   -------
a                                       0.19       0.14       0.11       0.08      0.06
b                                       0.14       0.14       0.14       0.13      0.12
c                                      -0.01      -0.02      -0.01      -0.01     -0.01
                                       Y=Emg        X=T
                            L=          0.31                 Y=Emg        X=T       X^2
                         500.00         0.24     500.00       0.24     500.00  ********
                         750.00         0.19     750.00       0.19     750.00  ********
                        1000.00         0.18    1000.00       0.18    1000.00  ********
                        1500.00         0.15    1500.00       0.15    1500.00  ********
                        2000.00         0.12    2000.00       0.12    2000.00  ********
                        2500.00         0.09    2500.00       0.09    2500.00  ********
                        3000.00         0.07    3000.00       0.07    3000.00  ********
                        3500.00         0.06    3500.00       0.06    3500.00  ********
                        4000.00         0.05    4000.00       0.05    4000.00  ********
                                 -----------   --------   --------   --------   -------
                                      500.00                  1.16   18750.00  ********
                                                                 Y          X       X#2

CO2g1                                 500.00    1000.00    1500.00    2000.00   2500.00
--------------------             --------   --------   --------   --------   -------
a                                       0.11       0.09       0.10       0.09      0.08
b                                       0.04       0.05       0.05       0.06      0.06
c                                      -0.00      -0.01      -0.01      -0.01     -0.01

                                       Y=Emg        X=T
                            L=          0.19                 Y=Emg        X=T       X^2
                         500.00         0.12     500.00       0.12     500.00  ********
                        1000.00         0.09    1000.00       0.09    1000.00  ********
                        1500.00         0.11    1500.00       0.11    1500.00  ********
                        2000.00         0.11    2000.00       0.11    2000.00  ********
                                 -----------   --------   --------   --------   -------
                                      500.00                  0.43    5000.00  ********
                                                                 Y          X       X#2

                            L=          0.19                 Y=Emg        X=T       X^2
                        2500.00         0.09    2500.00       0.09    2500.00  ********
                        3000.00         0.07    3000.00       0.07    3000.00  ********
                        3500.00         0.06    3500.00       0.06    3500.00  ********
                        4000.00         0.05    4000.00       0.05    4000.00  ********
                                 -----------   --------   --------   --------   -------
                                      500.00                  0.26   13000.00  ********
                                                                 Y          X       X#2
***************************************************************************************
***************************************************************************************

H2Ogg2                                500.00    1000.00    1500.00    2000.00   2500.00
--------------------             --------   --------   --------   --------   -------
a                                       0.19       0.14       0.11       0.08      0.06
b                                       0.14       0.14       0.14       0.13      0.12
c                                      -0.01      -0.02      -0.01      -0.01     -0.01
                                       Y=Emg        X=T
```

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
56	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------									
57	3000.00	3500.00	4000.00	750.00															
58	--------	--------	--------	--------															
59	0.04	0.03	0.02	0.15															
60	0.10	0.08	0.07	0.15															
61	-0.01	-0.01	-0.01	-0.02															
62																			
63	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg									
64	*******************		117.92	58961.06	1.00	B =	-0.00	500.00	0.23	0.24									
65	*******************		145.99	109492.10	1.00	C =	4400.00	1000.00	0.18	0.18									
66	*******************		179.67	179665.66	1.00	D =	0.24	1500.00	0.15	0.15									
67	*******************		228.35	342529.50	1.00	E =	***********	2000.00	0.12	0.12									
68	*******************		242.77	485530.82	1.00			2500.00	0.09	0.09									
69	*******************		233.01	582516.95	1.00	a =	0.27	3000.00	0.07	0.07									
70	*******************		223.34	670034.19	1.00	b =	-0.00	3500.00	0.06	0.06									
71	*******************		208.92	731232.58	1.00	c =	0.00	4000.00	0.05	0.05									
72	*******************		186.67	746675.14	1.00			1641.97	0.14										
73	--------	--------	--------	--------	--------														
74	*******************		1766.64	3906638.01	9.00					*									
75	X#3	X#4	XY	X#2Y	N	EMGO1 = (EGCO2)+(GH2O))(1-CSO1)													
76								0.23											
77																			
78	3000.00	3500.00	4000.00																
79	--------	--------	--------																
80	0.06	0.05	0.04																
81	0.06	0.05	0.04																
82	-0.01	-0.00	-0.00																
83																			
84																			
85	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg							
86	*******************		60.09	30045.38	1.00	B =	-0.00	B =	-0.00	500.00	0.12	0.12							
87	*******************		94.37	94372.92	1.00	C =	2500.00	C =	6500.00	1000.00	0.10	0.09							
88	*******************		159.13	238697.72	1.00	D =	0.11	D =	0.16	1500.00	0.10	0.11							
89	*******************		211.04	422084.39	1.00	E =	***********	E =	***********	2000.00	0.11	0.11							
90	--------	--------	--------	--------	--------					2500.00	0.09	0.09							
91	*******************		524.64	785200.41	4.00	a =	0.15	a =	0.21	3000.00	0.07	0.07							
92	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.06	0.06							
93						c =	0.00	c =	0.00	4000.00	0.05	0.05							
94	X^3	X^4	XY	X^2Y	N					1641.97	0.10								
95	*******************		222.80	556996.45	1.00														
96	*******************		215.80	647386.30	1.00														
97	*******************		202.66	709308.35	1.00														
98	*******************		183.38	733524.90	1.00														
99	--------	--------	--------	--------	--------														
100	*******************		824.63	2647216.00	4.00														
101	X#3	X#4	XY	X#2Y	N														
102	**																		
103	**																		
104																			
105	3000.00	3500.00	4000.00	750.00															
106	--------	--------	--------	--------															
107	0.04	0.03	0.02	0.15															
108	0.10	0.08	0.07	0.15															
109	-0.01	-0.01	-0.01	-0.02															
110																			

	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
--	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------
56	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********
57																			
58	H2OW1	500 00	1000 00	1500 00	2000 00	******	3000 00	3500 00	******	750 00									
59	---------	--------	-------	--------	--------	-----	--------	--------	-----	--------									
60 a		0 19	0 14	0 11	0.08	0 06	0 04	0 03	0.02	0 15									
61 b		0 14	0.14	0 14	0.13	0.12	0 10	0.08	0.07	0 15									
62 c		-0 01	-0.02	-0.01	-0.01	-0.01	-0.01	-0 01	-0.01	-0.02									
63		Y=Emg	X=T																
64	t =	0.49		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	X=T	Y calc	Y act=Eg			
65	500.00	0.26	500 00	0 26	500.00	********	********	********	********	64747.54	1.00	B =	-0 00	500 00	0 25	0 26			
66	750.00	0.22	750.00	0 22	750 00	********	********	********	********	********	1.00	C =	4400.00	1000 00	0 21	0.20			
67	1000 00	0.20	1000 00	0 20	1000 00	********	********	********	********	********	1 00	D =	0 26	1500 00	0 17	0.18			
68	1500 00	0.18	1500 00	0 18	1500 00	********	********	********	********	********	1 00	E =	*********	2000 00	0.14	0 14			
69	2000 00	0 14	2000 00	0 14	2000.00	********	********	********	********	********	1 00			2500 00	0.11	0 11			
70	2500 00	0.11	2500.00	0 11	2500.00	********	********	********	********	********	1.00	a =	0 30	3000 00	0 09	0.09			
71	3000.00	0.09	3000 00	0 09	3000 00	********	********	********	********	********	1.00	b =	-0 00	3500 00	0 07	0.07			
72	3500 00	0.07	3500 00	0 07	3500 00	********	********	********	********	********	1.00	c =	0.00	4000 00	0 06	0 06			
73	4000.00	0.06	4000 00	0.06	4000.00	********	********	********	********	********	1 00			2587.64	0 11				
74		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------								
75		500.00		1.33	18750 00	********	********	********	********	********	9 00	ABGw1 = (ABCO2+ABH2O)(1-CSO1)							
76				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.15					
77												ABCO2 = (EMCO2 @ Tw, P*L*Tw/Tg)*(Tg/Tw).65							
78														0.06					
79	CO2W1	500.00	1000.00	1500.00	2000.00	******	3000 00	3500.00	******			ABH2O = (EMH2O @ Tw, P*L*Tw/Tg)*(Tg/Tw).45							
80	---------	--------	-------	--------	--------	-----	--------	--------	--------					0.09					
81 a		0.11	0 09	0 10	0.09	0.08	0 06	0.05	0.04										
82 b		0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04			Tg =		1641.97	PL1*Tw/Tg	0.49			
83 c		-0.00	-0.01	-0 01	-0.01	-0 01	-0.01	-0.00	-0.00			Tw =		2587 64	Csol =	0.03			
84																			
85		Y=Emg	X=T																
86	L=	0.21		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg	
87	500 00	0.12	500.00	0 12	500 00	********	********	********	60.51	30253.61	1.00	B =	-0 00	B =	-0.00	500.00	0.12	0.12	
88	1000.00	0.10	1000.00	0 10	1000 00	********	********	********	95.34	95343.59	1 00	C =	2500 00	C =	6500.00	1000.00	0.10	0.10	
89	1500 00	0 11	1500 00	0 11	1500 00	********	********	********	********	********	1.00	D =	0 12	D =	0 16	1500 00	0.10	0.11	
90	2000.00	0 11	2000.00	0 11	2000 00	********	********	********	********	********	1 00	E =	*********	E =	*********	2000.00	0 11	0 11	
91		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------					2500.00	0.09	0.09	
92		500 00		0 43	5000 00	********	********	********	********	********	4 00	a =	0 15	a =	0 21	3000 00	0 07	0 07	
93				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500 00	0 06	0 06	
94												c =	0 00	c =	0 00	4000.00	0.05	0.05	
95	L =	0 21		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					2587 64	0 09		
96	2500 00	0.09	2500 00	0.09	2500.00	********	********	********	********	********	1 00								
97	3000.00	0 07	3000.00	0.07	3000 00	********	********	********	********	********	1.00								
98	3500 00	0.06	3500.00	0 06	3500.00	********	********	********	********	********	1.00								
99	4000.00	0 05	4000.00	0.05	4000.00	********	********	********	********	********	1.00								
100		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------								
101		500.00		0.27	13000.00	********	********	********	********	********	4.00								
102				Y	X	X#2	X#3	X#4	XY	X#2Y	N								
103	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********			
104																			
105	H2OS2	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******	750.00									
106	---------	--------	-------	--------	--------	-----	--------	--------	-----	--------									
107 a		0 19	0 14	0 11	0 08	0.06	0.04	0.03	0.02	0.15									
108 b		0 14	0 14	0 14	0 13	0 12	0.10	0.08	0.07	0.15									
109 c		-0 01	-0 02	-0 01	-0 01	-0 01	-0.01	-0 01	-0.01	-0 02									
110		Y=Emg	X=T																

```
                   A          B              C           D            E            F           G          H         I            J       K              L          M          N          O          P        Q
-- ---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
111 Qws+Qwm+Qwg+Qwl =                       (0)    Emw =        0 80                 /ppre~aglltl~gpq(Goto)C~(Righ           |                        L=       0 63                 Y=Emg       X=T       X^2
112 Qgs+Qgm+Qgg+Qgl =                        0     FLF =        0 80                 /pprrad~aypQ/WCS12~/PPRH~ACPq           |                    500 00       0.28     500 00       0 28     500.00 ********
113 Qls+Qlm+Qlg+Qll =                        0     EMl =        1 00                 /pprconst~agppq                         |                    750 00       0 24     750 00       0 24     750 00 ********
114                                                                                                           ALT C              |                   1000 00       0 22    1000.00       0.22    1000 00 ********
115  Ts =Tw = Tg                                                                         ALT F              (Calc)/XG            |                   1500 00       0 19    1500.00       0 19    1500.00 ********
116 ------------                                                                         /PPRFLA~ACRFLAT~GREC~GPRECB~A           |                   2000 00       0.16    2000.00       0 16    2000.00 ********
117     Qws = Qsw   (39.623)      (9.277)                30 346                                                                  |                   2500 00       0.13    2500 00       0.13    2500.00 ********
118     Qgs = Qsg    (6.104)      (8 930)                (2 825)                             alt H                               |                   3000 00       0 10    3000 00       0.10    3000 00 ********
119     Qgw = Qwg   (23.248)     (92.803)               (69.554)                 /ppri~agr8~GPR4~GR4A~GPPQ                                           3500 00       0.08    3500.00       0.08    3500.00 ********
120     Qls = Qsl  (142.433)     (22 378)               120 055                                                                  |                   4000 00       0 07    4000 00       0 07    4000.00 ********
121      Qlw =Qwl  (507.096)    (340.001)               167.095                  print macro \p                                  |                          -----------  --------   --------   --------  -------
122     Qlg = Qgl   (78.322)     (23.150)                55 172                  /pprrad~agppq                                                                500.00                  1.46   18750.00 ********
123 Qs             (162.280)                                                                                                     |                                                         Y          X      X#2
124 Qw                  (39)                   alt s                             print const \r                                  |
125 Qg             (165.074)           /FSA FKILN~R/FSC FKILN~R                  /pprconst~agllllq                               |
126 Ql               342.322                                                     /pprH~agppq                                     |       CO2g2                    500 00    1000 00    1500 00    2000 00  2500 00
127                   14 929                                                                                                     |       -------------------    --------   --------   --------   --------  -------
128                                                                              /PPREMT1~ACPPREMT2~ACPPQ                        |       a                          0 11       0 09       0 10       0 09     0 08
129                Qs = ssts + wstw + gstg + lstl + hcvwstTw    29-Feb                                                           |       b                          0 04       0 05       0 05       0 06     0 06
130                                                                              /rnc{r}~~(End){Down}{End}{Dow                   |       c                         -0 00      -0 01      -0 01      -0 01    -0 01
131                Qw = swts + wwtw + gwtg + fwtl + hcvgwlTg - Tw) - hcdwsh(Tw - Tsh)                                            |
132                                                                                                                              |                                Y=Emg        X=T
133                Qg = sgts + wgtw + ggtg  + fgtl - hcvgs(T      FLF =         0 80                                             |                        L=       0 38                 Y=Emg       X=T       X^2
134                                                               EMS =         0 80                                             |                    500 00       0 13     500 00       0 13     500 00 ********
135                Ql = slts + wltw + gltg  + lltl                Emw =         0 80                                             |                   1000 00       0 10    1000 00       0.10    1000.00 ********
136                Qs                                             EMl =         1.00                                             |                   1500 00       0 11    1500.00       0 11    1500 00 ********
137                ***************************************       watts       BTU/HR               *******************                               2000 00       0.12    2000.00       0 12    2000 00 ********
138                                                                                                                                      |                          -----------  --------   --------   --------  -------
139 Es             SS        EMS*AS                      0 6615                                                                      |                            500.00                  0.46    5000 00 ********
140                   2 00 -ABS*TRgS2*FwS*Fsw*pw        -0 0024                                                                      |                                                      Y          X      X#2
141                   3.00 -ABS*TRgS3*FwS*Fww*FS        -0 0001                                                                      |
142                   4 00 -FwS*TRgS3*Fww*Fww*FS        -0 0000                                                                      |                        L=       0.38                 Y=Emg       X=T       X^2
143                   5.00 -FwS*TRgS3*FwS*Fsw*FS        -0.0000                                                                      |                   2500 00       0.10    2500.00       0.10    2500.00 ********
144 Qs <= Qs                                             0 6590     40.585     138.558                                               |                   3000 00       0.08    3000.00       0.08    3000.00 ********
145                                                                                                                                  |                   3500 00       0.07    3500.00       0.07    3500.00 ********
146 Ew             wS        -ABS*TRgw1*FwS*Emw*Aw      -0.1541                                                                      |                   4000.00       0.05    4000.00       0.05    4000.00 ********
147                   2.00 -ABS*TRgw2*FwS*Fww*pw        -0.0088                                                                      |                          -----------  --------   --------   --------  -------
148                   3.00 -ABS*TRgw3*FwS*Fww*Fw        -0.0005                                                                      |                            500.00                  0.30   13000.00 ********
149                   4 00 -ABS*TRgw3*FwS*FwS*FS        -0.0002                                                                      |                                                      Y          X      X#2
150                   5 00 -Fws*TRgw3*Fww*Fww*Fw -0.000039                                                                           | ***************************************************************************
151                   6.00 -2*FwS*TRgw3*FwS*Fww*        -0.0000                                                                      |
152 Qs <= Qw                                            -0.1636   (39.623)   (135.273)                                               | H2Ogg3                   500.00    1000.00    1500.00    2000.00  2500.00
153                                                                                                                                  | -------------------    --------   --------   --------   --------  -------
154 Eg             gS        -ABS*Emg*AS                -0.1535                                                                      | a                          0.19       0.14       0.11       0.08     0.06
155                   2 00 -ABS*FwS*pw*TRgS11*EM        -0.0020                                                                      | b                          0 14       0 14       0.14       0 13     0.12
156 Qs <= Qg                                            -0.1555    (6.104)    (20.840)                                               | c                         -0 01      -0.02      -0.01      -0.01    -0.01
157                                                                                                                                  |                          Y=Emg        X=T
158            El ls         -ABS*TRgl1*FlS*Eml*Al      -0 3950                                                                      |                  L=       0 94                 Y=Emg       X=T       X^2
159                   2 00 -ABS*TRgl3*pS*pw*FlS*        -0.0005                                                                      |              500 00       0 31     500.00       0 31     500 00 ********
160                   3 00 -TRgl3*pS*pw*pw*FlS*F        -0 0000                                                                      |              750 00       0 27     750 00       0 27     750 00 ********
161                   4 00 -ABS*TRgl2*pw*Flw*FwS        -0 0246                                                                      |             1000 00       0 26    1000 00       0.26    1000 00 ********
162                   5 00 -ABS*TRgl3*pw*pw*Flw*        -0 0015                                                                      |             1500 00       0 23    1500 00       0 23    1500.00 ********
163                   6 00 -TRgl3*pw*pw*pw*Flw*F        -0 0001                                                                      |             2000 00       0 19    2000 00       0 19    2000.00 ********
164                   7 00 -TRgl3*pw*pw*pS*Flw*F        -0 0000                                                                      |             2500 00       0 16    2500 00       0 16    2500.00 ********
165                                                     -0 4218  (142 433)   (486.267)                                               |             3000 00       0 13    3000 00       0 13    3000 00 ********
```

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
111	X^3	X^4	XY	X^2Y	N	A =	0 00	X=T	Y calc	Y act=Eg									
112	********************		137 71	68853 70	1.00	B =	-0 00	500 00	0 27	0 28									
113	********************		176 63	132474 76	1 00	C =	4400 00	1000 00	0 22	0 22									
114	********************		219 96	219956 46	1.00	D =	0 28	1500 00	0 19	0 19									
115	********************		287 40	431096 15	1 00	E =	***********	2000 00	0 16	0 16									
116	********************		315 69	631381 21	1 00			2500 00	0 13	0 13									
117	********************		315 08	787697 13	1 00	a =	0 31	3000 00	0 10	0 10									
118	********************		307 93	923786 35	1 00	b =	-0 00	3500 00	0 08	0 08									
119	********************		291 53	1020363.37	1 00	c =	0.00	4000 00	0 07	0.07									
120	********************		270.48	1081919 70	1.00			1641 97	0.18										
121	--------	--------	--------	--------	--------														
122	********************		2322 40	5297528 84	9 00	ABgg2 = (ABCO2+ABH2O)(1-CSO1)													
123	X#3	X#4	XY	X#2Y	N			0 2726											
124						ABCO2 = (EMCO2 @ Ts. P*L*Ts/Tg)*(Tg/Ts).65													
125								0 11											
126	3000 00	3500.00	4000 00			ABH2O = (EMH2O @ Ts P*L*Ts/Tg)*(Tg/Ts).45													
127	--------	--------	--------					0 18											
128	0.06	0 05	0 04																
129	0 06	0 05	0 04			Tg =		1641 97	plo2 =	0 18									
130	-0 01	-0 00	-0 00				Tg =	1641 97 Csog2 =		0.0512									
131																			
132																			
133	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0 00	X=T	Y calc	Y act=Eg							
134	********************		63 52	31758.50	1.00	B =	-0.00	B =	-0.00	500.00	0 12	0 13							
135	********************		102.34	102337 14	1.00	C =	2500.00	C =	6500 00	1000 00	0 11	0 10							
136	********************		171.74	257607.59	1.00	D =	0.12	D =	0 18	1500.00	0 11	0 11							
137	********************		232.22	464445.00	1.00	E =	***********	E =	***********	2000.00	0.12	0 12							
138	--------	--------	--------	--------	--------					2500.00	0.10	0 10							
139	********************		569.82	856148.23	4.00	a =	0 15	a =	0.22	3000.00	0.08	0 08							
140	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0.00	3500.00	0.07	0 07							
141						c =	0.00	c =	0.00	4000.00	0 05	0 05							
142	X^3	X^4	XY	X^2Y	N					1641.97	0.11								
143	********************		249.74	624355.40	1.00														
144	********************		245.74	737212.64	1.00														
145	********************		231.37	809789.01	1.00														
146	********************		209.36	837450.63	1.00														
147	--------	--------	--------	--------	--------														
148	********************		936.21	3008807.67	4.00														
149	X#3	X#4	XY	X#2Y	N														
150	**																		
151																			
152	3000.00	3500.00	4000.00	750.00															
153	--------	--------	--------	--------															
154	0.04	0.03	0 02	0.15															
155	0.10	0 08	0 07	0 15															
156	-0.01	-0.01	-0.01	-0 02															
157																			
158	X^3	X^4	XY	X^2Y	N	A =	0 00	X=T	Y calc	Y act=Eg									
159	********************		156 04	78018 03	1 00	B =	-0 00	500.00	0.30	0.31									
160	********************		204 75	153563 25	1.00	C =	4400 00	1000 00	0 26	0.26									
161	********************		257 05	257046 12	1 00	D =	0.32	1500.00	0 22	0.23									
162	********************		342.11	513163 19	1.00	E =	***********	2000 00	0 19	0.19									
163	********************		383 22	766439 03	1 00			2500 00	0 16	0.16									
164	********************		391 00	977510 85	1 00	a =	0 35	3000 00	0 13	0.13									
165	********************		386 49	1159467 98	1 00	b =	-0 00	3500 00	0 11	0 11									

	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
111	L=	0.70		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg			|
112	500.00	0.28	500.00	0.28	500.00	**********	**********	**********	**********	71103.60	1.00	B =	-0.00	500.00	0.28	0.28			|
113	750.00	0.24	750.00	0.24	750.00	**********	**********	**********	**********	**********	1.00	C =	4400.00	1000.00	0.23	0.23			|
114	1000.00	0.23	1000.00	0.23	1000.00	**********	**********	**********	**********	**********	1.00	D =	0.29	1500.00	0.20	0.20			|
115	1500.00	0.20	1500.00	0.20	1500.00	**********	**********	**********	**********	**********	1.00	E =	*********	2000.00	0.16	0.17			|
116	2000.00	0.17	2000.00	0.17	2000.00	**********	**********	**********	**********	**********	1.00			2500.00	0.13	0.13			|
117	2500.00	0.13	2500.00	0.13	2500.00	**********	**********	**********	**********	**********	1.00	a =	0.32	3000.00	0.11	0.11			|
118	3000.00	0.11	3000.00	0.11	3000.00	**********	**********	**********	**********	**********	1.00	b =	-0.00	3500.00	0.09	0.09			|
119	3500.00	0.09	3500.00	0.09	3500.00	**********	**********	**********	**********	**********	1.00	c =	0.00	4000.00	0.07	0.07			|
120	4000.00	0.07	4000.00	0.07	4000.00	**********	**********	**********	**********	**********	1.00			1837.60	0.17				|
121		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------								|
122		500.00		1.53	18750.00	**********	**********	**********	**********	**********	9.00		ABgS2 = (ABCO2+ABH2O)(1-CSO1)						|
123				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.26					|
124													AHCO2 = (EMCO2 @ Ts. P*L*Ts/Tg)*(Tg/Ts) .65						|
125														0.11					|
126	CO2S2	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******				ABH2O = (EwH2O @ Ts P*L*Ts/Tg)*(Tg/Ts) .45						|
127	---------	--------	-------	--------	--------	-----	--------	--------	--------					0.17					|
128	a	0.11	0.09	0.10	0.09	0.08	0.06	0.05	0.04										|
129	b	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04				Tg =	1641.97	PL2*Ts/Tg	0.70			|
130	c	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00				Ts =	1837.60	Cso2 =	0.05			|
131																			|
132		Y=Emg	X=T																|
133	L=	0.43		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg	|
134	500.00	0.13	500.00	0.13	500.00	**********	**********	**********	64.31	32155.14	1.00	B =	-0.00	B =	-0.00	500.00	0.13	0.13	|
135	1000.00	0.10	1000.00	0.10	1000.00	**********	**********	**********	**********	**********	1.00	C =	2500.00	C =	6500.00	1000.00	0.11	0.10	|
136	1500.00	0.12	1500.00	0.12	1500.00	**********	**********	**********	**********	**********	1.00	D =	0.12	D =	0.18	1500.00	0.11	0.12	|
137	2000.00	0.12	2000.00	0.12	2000.00	**********	**********	**********	**********	**********	1.00	E =	*********	E =	*********	2000.00	0.12	0.12	|
138		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------					2500.00	0.10	0.10	|
139		500.00		0.47	5000.00	**********	**********	**********	**********	**********	4.00	a =	0.15	a =	0.22	3000.00	0.08	0.08	|
140				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.07	0.07	|
141												c =	0.00	c =	0.00	4000.00	0.05	0.05	|
142	L=	0.43		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1837.60	0.12		|
143	2500.00	0.10	2500.00	0.10	2500.00	**********	**********	**********	**********	**********	1.00								|
144	3000.00	0.08	3000.00	0.08	3000.00	**********	**********	**********	**********	**********	1.00								|
145	3500.00	0.07	3500.00	0.07	3500.00	**********	**********	**********	**********	**********	1.00								|
146	4000.00	0.05	4000.00	0.05	4000.00	**********	**********	**********	**********	**********	1.00								|
147		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------								|
148		500.00		0.31	13000.00	**********	**********	**********	**********	**********	4.00								|
149				Y	X	X#2	X#3	X#4	XY	X#2Y	N								|
150	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********	**********			|
151																			|
152	H2O2W	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******	750.00									|
153	---------	--------	-------	--------	--------	-----	--------	--------	-----	--------									|
154	a	0.19	0.14	0.11	0.08	0.06	0.04	0.03	0.02	0.15									|
155	b	0.14	0.14	0.14	0.13	0.12	0.10	0.08	0.07	0.15									|
156	c	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02									|
157		Y=Emg	X=T																|
158	L=	0.99		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg			|
159	500.00	0.32	500.00	0.32	500.00	**********	**********	**********	**********	79346.16	1.00	B =	-0.00	500.00	0.31	0.32			|
160	750.00	0.28	750.00	0.28	750.00	**********	**********	**********	**********	**********	1.00	C =	4400.00	1000.00	0.27	0.26			|
161	1000.00	0.26	1000.00	0.26	1000.00	**********	**********	**********	**********	**********	1.00	D =	0.33	1500.00	0.23	0.23			|
162	1500.00	0.23	1500.00	0.23	1500.00	**********	**********	**********	**********	**********	1.00	E =	*********	2000.00	0.19	0.20			|
163	2000.00	0.20	2000.00	0.20	2000.00	**********	**********	**********	**********	**********	1.00			2500.00	0.16	0.16			|
164	2500.00	0.16	2500.00	0.16	2500.00	**********	**********	**********	**********	**********	1.00	a =	0.36	3000.00	0.13	0.13			|
165	3000.00	0.13	3000.00	0.13	3000.00	**********	**********	**********	**********	**********	1.00	b =	-0.00	3500.00	0.11	0.11			|

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
166												3500 00	0 11	3500 00	0 11	3500 00	********
167		hcvws	+hcvws*(THIrad*D/2)*(		19200	(19 200)	(65 547)					4000 00	0 09	4000 00	0 09	4000 00	********
168		hcvgs	+hcvgs*As*(Tg-Ts)		-4494	4 494	15 342						-----------	--------	--------	--------	-------
169						***********							500 00		1 74	18750 00	********
170	Qs =>					(162 280)	(554 025)								Y	X	X#2
171																	
172		Qw		0 34													
173		**********	**********	**********	**********						CO2g3		500 00	1000 00	1500 00	2000 00	2500 00
174											----------	----------	--------	--------	--------	--------	-------
175		sw	-ABw*TRgs1*Fsw*EMS*AS		-0 1418						a		0 11	0 09	0 10	0 09	0 08
176		2 00	-ABw*TRgs2*Fww*Fsw*pw		-0 0082						b		0 04	0 05	0 05	0.06	0 06
177	Es	1 98	-ABw*TRgs3*Fww*Fww*Fs		-0 0005						c		-0 00	-0 01	-0 01	-0 01	-0 01
178		4 00	-ABw*TRgs3*Fws*Fsw*Fs		-0.0002												
179		5 00	-Fww*TRgs3*Fww*Fww*Fs		-0 000036								Y=Emg	X=T			
180		6 00	-2*Fww*TRgs3*Fws*Fsw*		-0 0000							L=	0 57		Y=Emg	X=T	X^2
181	Qw <= Qs				-0 1506	(9 277)	(31 672)					500 00	0 13	500 00	0 13	500 00	********
182												1000 00	0 11	1000 00	0 11	1000.00	********
183		ww	+Emw*Aw		2 5148							1500 00	0 12	1500 00	0 12	1500.00	********
184	fw	2 00	-ABw*TRgw1*Fww*Emw*Aw		-0 5210							2000 00	0 13	2000 00	0 13	2000 00	********
185	f * fww	3 00	-ABw*TRgw2*Fww*Fww*pw		-0 0298								-----------	--------	--------	--------	-------
186		4 00	-ABw*TRgw2*Fws*Fsw*ps		-0.0099								500 00		0 49	5000.00	********
187		5 00	-ABw*TRgw3*Fww*Fww*Fw		-0 0017										Y	X	X#2
188		6.00	-2*ABw*TRgw3*Fws*Fww*		-0 0011												
189		7 00	-Fww*TRgw3*Fww*Fww*Fw		-0 0001							L=	0 57		Y=Emg	X=T	X^2
190		8 00	-2*Fww*TRgw3*Fws*Fww*		-0 0001							2500 00	0 11	2500 00	0 11	2500 00	********
191		9 00	-Fsw*TRgw3*Fww*Fww*Fw		-0 0000							3000 00	0 09	3000.00	0 09	3000.00	********
192		10 00	-Fsw*TRgw3*Fws*Fws*Fs		-0 0000							3500 00	0.07	3500 00	0 07	3500 00	********
193	Qw <= Qw				1 9509	472 427	1 612 866					4000 00	0 06	4000 00	0 06	4000 00	********
194													-----------	--------	--------	--------	-------
195	Eg	gw	-ABw*Emg*Aw		-0 5836								500 00		0 33	13000 00	********
196		2.00	-ABw*Fmm*pw*TRgw11*Em		-0 0066	f									Y	X	X#2
197		3.00	-ABw*Fsm*ps*TRgw11*Em		-0.0020						**********	**********	**********	**********	**********	**********	**********
198	Qw <= Qg				-0.5922	(23.248)	(79.370)										
199											H2Ogf1		500.00	1000.00	1500 00	2000.00	2500.00
200	Ef	fw	-ABw*TRgf2*ps*Ffs*Fsw		-0 0267						----------	----------	--------	--------	--------	--------	-------
201		2.00	-ABw*TRgf3*ps*pw*Ffs*		-0.0016						a		0.19	0.14	0.11	0.08	0.06
202		3.00	-TRgf3*ps*pw*pw*Ffs*F		-0.0001						b		0.14	0.14	0.14	0.13	0.12
203		4.00	-TRgf3*ps*ps*pw*Ffs*F		-0 0000						c		-0.01	-0 02	-0.01	-0.01	-0.01
204		5.00	-ABw*TRgf1*Ffw*EMf*Af		-1.3827								Y=Emg	X=T			
205		6.00	-ABw*TRgf2*pw*Ffw*Fww		-0.0833							L=	0.09		Y=Emg	X=T	X^2
206		7.00	-ABw*TRgf3*pw*pw*Ffw*		-0.00501							500.00	0.21	500 00	0.21	500.00	********
207		8 00	-ABw*TRgf3*pw*ps*Ffw*		-0.0017							750.00	0.16	750.00	0.16	750.00	********
208		9.00	-TRgf3*pw*pw*ps*Ffw*F		-0.0001							1000.00	0.15	1000.00	0.15	1000.00	********
209		10.00	-TRgf3*pw*pw*ps*Ffw*F		-0.0001							1500.00	0.12	1500.00	0 12	1500.00	********
210		11.00	-TRgf3*pw*pw*pw*Ffw*F		-0.0004							2000.00	0.09	2000.00	0.09	2000.00	********
211					-1.5017	(507.096)	(1,731,227)					2500.00	0.07	2500.00	0.07	2500.00	********
212												3000.00	0.05	3000.00	0 05	3000.00	********
213		hcvws	+hcvws*(THIrad*D/2)*(		19200	19.200	65.547					3500.00	0.04	3500.00	0.04	3500.00	********
214		hcvgw	+hcvgw*Aw*(Tg-Tw)		-33030	33.030	112.763					4000.00	0.03	4000 00	0.03	4000.00	********
215		hcdwsh	+hcdwsh*area3*(Tw-Tsh		14928	14.928	50.963						-----------	--------	--------	--------	-------
216						***********							500 00		0.93	18750.00	********
217	Qw =>					(39)	(134)								Y	X	X#2
218																	
219		Qg															
220		**********	**********	**********	**********	29-Feb					CO2g2		500.00	1000.00	1500.00	2000 00	2500.00

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
166	******************		368.41	1289439.07	1.00	C =	0.00	4000.00	0.09	0.09									
167	******************		348.26	1393035.27	1.00			1641.97	0.21										
168	--------	--------	--------	--------	--------														
169	******************		2837.33	6587682.79	9.00	ABgg3 = (ABCO2+ABH2O)(1-CSO1)													
170	X#3	X#4	XY	X#2Y	N			0.3103											
171						ABCO2 = (EMCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts).65													
172								0.12											
173	3000.00	3500.00	4000.00			ABH2O = (EMH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts).45													
174	--------	--------	--------					0.21											
175	0.06	0.05	0.04																
176	0.06	0.05	0.04			Tg =		1641.97	ploz =	0.57									
177	-0.01	-0.00	-0.00				Tg =	1641.97 Csog2 =		0.06									
178																			
179																			
180	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg							
181	******************		66.79	33393.11	1.00	B =	-0.00	B =	-0.00	500.00	0.13	0.13							
182	******************		109.89	109886.83	1.00	C =	2500.00	C =	6500.00	1000.00	0.12	0.11							
183	******************		183.75	275627.28	1.00	D =	0.13	D =	0.20	1500.00	0.12	0.12							
184	******************		252.32	504645.20	1.00	E =	***********	E =	************	2000.00	0.13	0.13							
185	--------	--------	--------	--------	--------					2500.00	0.11	0.11							
186	******************		612.75	923552.42	4.00	a =	0.16	a =	0.23	3000.00	0.09	0.09							
187	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.07	0.07							
188						c =	0.00	c =	0.00	4000.00	0.06	0.06							
189	X^3	X^4	XY	X^2Y	N					1641.97	0.12								
190	******************		275.38	688460.51	1.00														
191	******************		274.29	822875.28	1.00														
192	******************		258.86	905998.50	1.00														
193	******************		234.34	937369.96	1.00														
194	--------	--------	--------	--------	--------														
195	******************		1042.88	3354704.25	4.00														
196	X#3	X#4	XY	X#2Y	N														
197	******************	******************	******************	******************	******************	******************	******************	******************	******************	******************									
198																			
199	3000.00	3500.00	4000.00	750.00															
200	--------	--------	--------	--------															
201	0.04	0.03	0.02	0.15															
202	0.10	0.08	0.07	0.15															
203	-0.01	-0.01	-0.01	-0.02															
204																			
205	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg									
206	******************		102.92	51459.14	1.00	B =	-0.00	500.00	0.19	0.21									
207	******************		122.59	91940.03	1.00	C =	4400.00	1000.00	0.15	0.15									
208	******************		148.97	148968.25	1.00	D =	0.20	1500.00	0.12	0.12									
209	******************		183.59	275379.10	1.00	E =	***********	2000.00	0.09	0.09									
210	******************		187.45	374893.97	1.00			2500.00	0.07	0.07									
211	******************		170.70	426762.44	1.00	a =	0.24	3000.00	0.05	0.05									
212	******************		159.33	477978.69	1.00	b =	-0.00	3500.00	0.04	0.04									
213	******************		146.49	512727.21	1.00	c =	0.00	4000.00	0.03	0.03									
214	******************		123.20	492785.20	1.00			2811.90	0.06										
215	--------	--------	--------	--------	--------														
216	******************		1345.23	2852894.03	9.00	ABgf1 = (ABCO2+ABH2O)(1-CSO1)													
217	X#3	X#4	XY	X#2Y	N			0.0928											
218						ABCO2 = (EMCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts).65													
219								0.05											
220	3000.00	3500.00	4000.00			ABH2O = (EMH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts).45													

Row	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC
166	3500.00	0.11	3500.00	0.11	3500.00	************	************	************	************	************	1.00	C =	0.00	4000.00	0.09	0.09		
167	4000.00	0.09	4000.00	0.09	4000.00	************	************	************	************	************	1.00			2587.64	0.16			
168		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------							
169		500.00		1.78	18750.00	************	************	************	************	************	9.00	ABgw2 = (ABCO2+ABH2O)(1-CSO1)						
170				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.20				
171												ABCO2 = (EmCO2 @ Tw, P*L*Tw/Tg)*(Tg/Tw) 65						
172														0.08				
173	CO2W2	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******			ABH2O = (EmH2O @ Tw, P*L*Tw/Tg)*(Tg/Tw) 45						
174	---------	--------	-------	--------	--------	-----	--------	--------	--------					0.13				
175	a	0.11	0.09	0.10	0.09	0.08	0.06	0.05	0.04									
176	b	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04			Tg =		1641.97	PL(*Tw/Tg	0.99		
177	c	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00			Tw =		2587.64	Csol =	0.05		
178																		
179		Y=Emg	X=T															
180	T=	0.60		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg
181	500.00	0.13	500.00	0.13	500.00	************	************	************	67.27	33634.49	1.00	B =	-0.00	B =	-0.00	500.00	0.13	0.13
182	1000.00	0.11	1000.00	0.11	1000.00	************	************	************	************	************	1.00	C =	2500.00	C =	6500.00	1000.00	0.12	0.11
183	1500.00	0.12	1500.00	0.12	1500.00	************	************	************	************	************	1.00	D =	0.13	D =	0.20	1500.00	0.12	0.12
184	2000.00	0.13	2000.00	0.13	2000.00	************	************	************	************	************	1.00	E =	*********	E =	*********	2000.00	0.13	0.13
185		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------					2500.00	0.11	0.11
186		500.00		0.50	5000.00	************	************	************	************	************	4.00	a =	0.16	a =	0.23	3000.00	0.09	0.09
187				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.08	0.08
188												c =	0.00	c =	0.00	4000.00	0.06	0.06
189	L=	0.60		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					2587.64	0.11	
190	2500.00	0.11	2500.00	0.11	2500.00	************	************	************	************	************	1.00							
191	3000.00	0.09	3000.00	0.09	3000.00	************	************	************	************	************	1.00							
192	3500.00	0.08	3500.00	0.08	3500.00	************	************	************	************	************	1.00							
193	4000.00	0.06	4000.00	0.06	4000.00	************	************	************	************	************	1.00							
194		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------							
195		500.00		0.34	13000.00	************	************	************	************	************	4.00							
196				Y	X	X#2	X#3	X#4	XY	X#2Y	N							
197	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************		
198																		
199	H2O3S	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******	750.00								
200	---------	--------	-------	--------	--------	-----	--------	--------	-----	--------								
201	a	0.19	0.14	0.11	0.08	0.06	0.04	0.03	0.02	0.15								
202	b	0.14	0.14	0.14	0.13	0.12	0.10	0.08	0.07	0.15								
203	c	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02								
204		Y=Emg	X=T															
205	T=	1.05		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg		
206	500.00	0.32	500.00	0.32	500.00	************	************	************	************	81117.04	1.00	B =	-0.00	500.00	0.32	0.32		
207	750.00	0.29	750.00	0.29	750.00	************	************	************	************	************	1.00	C =	4400.00	1000.00	0.27	0.27		
208	1000.00	0.27	1000.00	0.27	1000.00	************	************	************	************	************	1.00	D =	0.34	1500.00	0.24	0.24		
209	1500.00	0.24	1500.00	0.24	1500.00	************	************	************	************	************	1.00	E =	*********	2000.00	0.20	0.20		
210	2000.00	0.20	2000.00	0.20	2000.00	************	************	************	************	************	1.00			2500.00	0.17	0.17		
211	2500.00	0.17	2500.00	0.17	2500.00	************	************	************	************	************	1.00	a =	0.36	3000.00	0.14	0.14		
212	3000.00	0.14	3000.00	0.14	3000.00	************	************	************	************	************	1.00	b =	-0.00	3500.00	0.11	0.11		
213	3500.00	0.11	3500.00	0.11	3500.00	************	************	************	************	************	1.00	c =	0.00	4000.00	0.09	0.09		
214	4000.00	0.09	4000.00	0.09	4000.00	************	************	************	************	************	1.00			1837.60	0.21			
215		---------	-------	--------	--------	-----	--------	--------	-----	--------	--------							
216		500.00		1.83	18750.00	************	************	************	************	************	9.00	ABgs3 = (ABCO2+ABH2O)(1-CSO1)						
217				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.30				
218												ABCO2 = (EmCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts) 65						
219														0.12				
220	CO2S3	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******			ABH2O = (EmH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts) 45						

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
221												--------------------	--------	--------	--------	--------	-------
222	Es	sg	-(1-TRgs1)*Ems*As		-0.1429						a		0.11	0.09	0.10	0.09	0.08
223		2.00	-(TRgs1-TRgs2)*Fsw*pw		-0.0019						b		0.04	0.05	0.05	0.06	0.06
224		3.00	-(TRgs2-TRgs3)*Fww*Fs		-0.0001						c		-0.00	-0.01	-0.01	-0.01	-0.01
225		4.00	-(TRgs2-TRgs3)*Fws*Fs		-0.0000												
226	Qg <= Qs				-0.1450	(8.930)	(30.486)						Y=Emg	X=T			
227												L=	0.09		Y=Emg	X=T	X^2
228	Ew	wg	-(1-TRgw1)*Emw*Aw		-0.3729							500.00	0.12	500.00	0.12	500.00	********
229		2.00	-(TRgw1-TRgw2)*Fww*pw		-0.0075							1000.00	0.09	1000.00	0.09	1000.00	********
230		3.00	-(TRgw2-TRgw3)*Fww*Fw		-0.0004							1500.00	0.10	1500.00	0.10	1500.00	********
231		4.00	-(TRgw2-TRgw3)*Fws*Fs		-0.0001							2000.00	0.10	2000.00	0.10	2000.00	********
232		5.00	-(TRgw2-TRgw3)*Fws*Fw		-0.0001							-----------		--------	--------	--------	-------
233		6.00	-(TRgw1-TRgw2)*Fws*ps		-0.0022								500.00		0.41	5000.00	********
234	Qg <= Qw				-0.3832	(92.803)	(316.828)								Y	X	X#2
235																	
236	Eg	gg	+Emg*Ag		1.4898							L=	0.09		Y=Emg	X=T	X^2
237		2.00	-ABg11*pw*Emg*Aw		-0.1186							2500.00	0.08	2500.00	0.08	2500.00	********
238		3.00	-(+pw*Fww+ps*Fws)*pw*		-0.0021							3000.00	0.07	3000.00	0.07	3000.00	********
239		4.00	-(+ABg11+pw*TRg11)*Fs		-0.0112							3500.00	0.05	3500.00	0.05	3500.00	********
240	Qg <= Qg	2a	-ABg11*ps*Fsf*As*Emg		-0.0205							4000.00	0.04	4000.00	0.04	4000.00	********
241					1.3373	52.503	179.245					-----------		--------	--------	--------	-------
242													500.00		0.25	13000.00	********
243	Ef	fg	1.0-(1-TRgf1)*EMf*Af		-0.2273										Y	X	X#2
244		2.00	-(TRgf1-TRgf2)*ps*Ffs		-0.0010						********	********	********	********	********	********	********
245		3.00	-(TRgf2-TRgf3)*ps*pw*		-0.0001												
246		4.00	-(TRgf1-TRgf2)*pw*Ffw		-0.0034						H2Ogf2		500.00	1000.00	1500.00	2000.00	2500.00
247		5.00	-(TRgf2-TRgf3)*pw*ps*		-0.0001						--------------------		--------	--------	--------	--------	-------
248		6.00	-(TRgf2-TRgf3)*pw*pw*		-0.0002						a		0.19	0.14	0.11	0.08	0.06
249					-0.2319	(78.322)	(267.393)				b		0.14	0.14	0.14	0.13	0.12
250											c		-0.01	-0.02	-0.01	-0.01	-0.01
251		hcvgs	+hcvgs*As*(Tg-Ts)		-4494	(4.494)	(15.342)						Y=Emg	X=T			
252		hcvgw	+hcvgw*Aw*(Tg-Tw)		-33030	(33.030)	(112.763)					L=	0.18		Y=Emg	X=T	X^2
253						***********						500.00	0.22	500.00	0.22	500.00	********
254	Qg =>					(165.074)	(563.561)					750.00	0.18	750.00	0.18	750.00	********
255												1000.00	0.16	1000.00	0.16	1000.00	********
256		Qf										1500.00	0.13	1500.00	0.13	1500.00	********
257	***					29-Feb						2000.00	0.11	2000.00	0.11	2000.00	********
258												2500.00	0.08	2500.00	0.08	2500.00	********
259		Es sf	-TRgs1*Fsf*EMs*As		-0.3414							3000.00	0.06	3000.00	0.06	3000.00	********
260		2.00	-TRgs2*pw*Fsw*Fwf*EMs		-0.0203							3500.00	0.05	3500.00	0.05	3500.00	********
261	Qf <= Qs	3.00	-TRgs3*pw*pw*Fsw*Fww*		-0.0012							4000.00	0.04	4000.00	0.04	4000.00	********
262		4.00	-TRgs3*pw*ps*Fsw*Fws*		-0.0004							-----------		--------	--------	--------	-------
263		5.00	-Fww*TRgs3*Fws*Fsf*Fs		-0.0000								500.00		1.02	18750.00	********
264		6.00	-Fwf*TRgs3*Fww*Fww*Fs		-0.0001										Y	X	X#2
265		7.00	-Fwf*TRgs3*Fws*Fsw*Fs		-0.0000												
266					-0.3634	(22.378)	(76.400)										
267											CO2g2		500.00	1000.00	1500.00	2000.00	2500.00
268		Ew wf	-TRgw1*Fwf*EMw*Aw		-1.2981						--------------------		--------	--------	--------	--------	-------
269		2.00	-TRgw2*pw*Fww*Fwf*Emw		-0.0744						a		0.11	0.09	0.10	0.09	0.08
270		3.00	-TRgw3*pw*pw*Fww*Fww*		-0.0043						b		0.04	0.05	0.05	0.06	0.06
271	Qf <= Qw	4.00	-TRgw3*pw*ps*Fww*Fws*		-0.0014						c		-0.00	-0.01	-0.01	-0.01	-0.01
272		5.00	-ps*TRgw2*Fws*Fsf*Emw		-0.0239												
273		6.00	-TRgw3*ps*pw*Fws*Fsw*		-0.0014								Y=Emg	X=T			
274		7.00	-Fsw*TRgw3*Fwl*Fww*Fw		-0.0001							L=	0.18		Y=Emg	X=T	X^2
275		8.00	-Fwf*TRgw3*Fww*Fww*Fw		-0.0003							500.00	0.12	500.00	0.12	500.00	********

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
221	--------	--------	--------					0 04				
222	0 06	0 05	0 04									
223	0 06	0 05	0 04			Tg =		1641 97	pIff =	0 05		
224	-0 01	-0 00	-0 00				Tl =	2811 90 Csogl =		0 03		
225												
226												
227	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0 00	X=T	Y calc	Y act=Eg
228	******************		58 21	29105.97	1.00	B =	-0 00	B =	-0 00	500 00	0 11	0 12
229	******************		89 99	89985.63	1.00	C =	2500 00	C =	6500 00	1000 00	0 10	0 09
230	******************		152 21	228318.87	1 00	D =	0 11	D =	0 15	1500 00	0 09	0 10
231	******************		199 38	398766.98	1.00	E = ***********		E = ***********		2000 00	0 10	0 10
232	--------	--------	--------	--------	--------					2500 00	0 08	0 08
233	******************		499 79	746177.44	4.00	a =	0 14	a =	0.21	3000 00	0 07	0 07
234	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0 00	3500 00	0 05	0 05
235						c =	0 00	c =	0 00	4000 00	0 04	0 04
236	X^3	X^4	XY	X^2Y	N					2811 90	0 07	
237	******************		208 00	519992 24	1 00							
238	******************		199 37	598110 54	1 00							
239	******************		186 96	654344 56	1.00							
240	******************		169 21	676843 28	1 00							
241	--------	--------	--------	--------	--------							
242	******************		763 53	2449290 62	4 00							
243	X#3	X#4	XY	X#2Y	N							
244	**											
245												
246	3000.00	3500.00	4000 00	750.00								
247	--------	--------	--------	--------								
248	0.04	0.03	0 02	0.15								
249	0.10	0.08	0.07	0.15								
250	-0 01	-0 01	-0.01	-0.02								
251												
252	X^3	X^4	XY	X^2Y	N	A =	0 00	X=T	Y calc	Y act=Eg		
253	******************		109.04	54518.32	1 00	B =	-0 00	500 00	0.21	0.22		
254	******************		132 15	99109.14	1.00	C =	4400 00	1000 00	0.17	0 16		
255	******************		161.50	161499 73	1.00	D =	0 22	1500.00	0.13	0.13		
256	******************		201.84	302760.87	1.00	E = ***********		2000.00	0.10	0.11		
257	******************		210.01	420013.24	1 00			2500.00	0 08	0.08		
258	******************		196.12	490291.89	1 00	a =	0 25	3000.00	0.06	0 06		
259	******************		185.42	556261.01	1 00	b =	-0.00	3500 00	0.05	0.05		
260	******************		171 93	601759.73	1.00	c =	0.00	4000.00	0.04	0.04		
261	******************		149.07	596286.10	1.00			2811.90	0.07			
262	--------	--------	--------	--------	--------							
263	******************		1517.07	3282500.02	9.00	ABgg3 = (ABCO2+ABH2O)(1-CSOl)						
264	X#3	X#4	XY	X#2Y	N			0 1016				
265						ABCO2 = (EMCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts).65						
266								0 05				
267	3000 00	3500 00	4000 00			ABH2O = (EMH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts).45						
268	--------	--------	--------					0.05				
269	0.06	0.05	0 04									
270	0.06	0 05	0.04			Ig =		1641 97	pIf2 =	0.10		
271	-0 01	-0 00	-0 00				Tg =	2811 90 Csog2 =		0.05		
272												
273												
274	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0 00	X=T	Y calc	Y act=Eg
275	******************		59 88	29940 85	1 00	B =	-0 00	B =	-0 00	500 00	0 12	0 12

Row	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
221	--------	--------	--------	--------	--------	--------	--------	--------	--------					0.20					
222	a	0.11	0.09	0.10	0.09	0.08	0.06	0.05	0.04										
223	b	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04			Tg =		1641.97	p(o) =	0.57			
224	c	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00			Ts =		1837.60	Cso3 =	0.06			
225																			
226		Y=Emg	X=T																
227	L=	0.64		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg	
228	500.00	0.14	500.00	0.14	500.00	********	********	********	67.92	33958.33	1.00	B =	-0.00	B =	-0.00	500.00	0.13	0.14	
229	1000.00	0.11	1000.00	0.11	1000.00	********	********	********	********	********	1.00	C =	2500.00	C =	6500.00	1000.00	0.12	0.11	
230	1500.00	0.13	1500.00	0.13	1500.00	********	********	********	********	********	1.00	D =	0.13	D =	0.20	1500.00	0.12	0.13	
231	2000.00	0.13	2000.00	0.13	2000.00	********	********	********	********	********	1.00	E =	********	E =	********	2000.00	0.13	0.13	
232		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------					2500.00	0.11	0.11	
233		500.00		0.50	5000.00	********	********	********	********	********	4.00	a =	0.16	a =	0.23	3000.00	0.09	0.09	
234				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.08	0.08	
235												c =	0.00	c =	0.00	4000.00	0.06	0.06	
236	L=	0.64		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1837.60	0.13		
237	2500.00	0.11	2500.00	0.11	2500.00	********	********	********	********	********	1.00								
238	3000.00	0.09	3000.00	0.09	3000.00	********	********	********	********	********	1.00								
239	3500.00	0.08	3500.00	0.08	3500.00	********	********	********	********	********	1.00								
240	4000.00	0.06	4000.00	0.06	4000.00	********	********	********	********	********	1.00								
241		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------								
242		500.00		0.35	13000.00	********	********	********	********	********	4.00								
243				Y	X	X#2	X#3	X#4	XY	X#2Y	N								
244	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********			
245		********	********	********	********	********	********	********	********	********	********	********	********	********	********	********			
246	H2O3W	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******	750.00									
247	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------									
248	a	0.19	0.14	0.11	0.08	0.06	0.04	0.03	0.02	0.15									
249	b	0.14	0.14	0.14	0.13	0.12	0.10	0.08	0.07	0.15									
250	c	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02									
251		Y=Emg	X=T																
252	L=	1.48		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg			
253	500.00	0.37	500.00	0.37	500.00	********	********	********	********	92135.95	1.00	B =	-0.00	500.00	0.36	0.37			
254	750.00	0.33	750.00	0.33	750.00	********	********	********	********	********	1.00	C =	4400.00	1000.00	0.32	0.31			
255	1000.00	0.31	1000.00	0.31	1000.00	********	********	********	********	********	1.00	D =	0.39	1500.00	0.28	0.28			
256	1500.00	0.28	1500.00	0.28	1500.00	********	********	********	********	********	1.00	E =	********	2000.00	0.24	0.24			
257	2000.00	0.24	2000.00	0.24	2000.00	********	********	********	********	********	1.00			2500.00	0.20	0.20			
258	2500.00	0.20	2500.00	0.20	2500.00	********	********	********	********	********	1.00	a =	0.41	3000.00	0.17	0.17			
259	3000.00	0.17	3000.00	0.17	3000.00	********	********	********	********	********	1.00	b =	-0.00	3500.00	0.14	0.14			
260	3500.00	0.14	3500.00	0.14	3500.00	********	********	********	********	********	1.00	c =	0.00	4000.00	0.11	0.12			
261	4000.00	0.12	4000.00	0.12	4000.00	********	********	********	********	********	1.00			2587.64	0.20				
262		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------								
263		500.00		2.17	18750.00	********	********	********	********	********	9.00	ABgw3 = (ABCO2+ABH2O)(1-CSO1)							
264				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.24					
265												ABCO2 = (EMCO2 @ Tw, P*L*Tw/Tg)*(Tg/Tw).65							
266														0.09					
267	CO2W3	500.00	1000.00	1500.00	2000.00	******	3000.00	3500.00	******			ABH2O = (EMH2O @ Tw, P*L*Tw/Tg)*(Tg/Tw).45							
268	--------	--------	--------	--------	--------	--------	--------	--------	--------					0.16					
269	a	0.11	0.09	0.10	0.09	0.08	0.06	0.05	0.04										
270	b	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04			Tg =		1641.97	PL1*Tw/Tg	1.48			
271	c	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00			Tw =		2587.64	Cso3 =	0.06			
272																			
273		Y=Emg	X=T																
274	L=	0.90		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg	
275	500.00	0.14	500.00	0.14	500.00	********	********	********	72.06	36032.35	1.00	B =	0.00	B =	-0.00	500.00	0.14	0.14	

```
          A        B            C          D          E           F           G
-- ------------------------------------------------------------------------------------
276               9 00 -Fww*TRgw3*Fws*Fww*Fs    -0 0001
277              10 00 -Fwl*TRgw3*Fws*Fww*Fs    -0 0001
278              11 00 -Fsl*TRgw3*Fws*Fws*Fs    -0 0000
279                                             -1.4040   (340.001)(1 160.765)
280
281         Ig gl       -Al*Emg                 -0 5684
282               2 00 -TRgl1l*pw*Fwl*Aw*Emg    -0 0165
283     Ql <= Qg  3 00 -TRgl1l*ps*Fsl*As*Emg    -0 0047
284                                             -0 5897    (23.150)   (79.035)
285
286         Il Il       +Eml*Al                  2 4494
287               2 00 -TRgl2*ps*Fsl*Fls*Eml    -0 0644
288               3 00 -TRgl3*ps*pw*Fls*Fsw*    -0 0040
289     Ql <= Ql  4 00 -TRgl2*pw*Flw*Fwl*Eml    -0 2075
290               5 00 -TRgl3*pw*pw*Flw*Fww*    -0 0125
291               6 00 -TRgl3*pw*ps*Flw*Fws*    -0 0040
292               7 00 -TRgl3*pw*pw*pw*Flw*F    -0 0008
293               8 00 -TRgl3*pw*pw*ps*Flw*F    -0 0003
294               9 00 -TRgl3*ps*pw*pw*Fls*F    -0 0002
295              10 00 -TRgl3*pw*pw*ps*Flw*F    -0 0002
296              11 00 -TRgl3*ps*ps*pw*Fls*F    -0 0001
297                                              2 1555    727 852  2.464 887
298       Qf =>                                 ***************************
299                                                        342.322  1.168.687
300
301 ***********************************************************
302
303                    Qs =                               (162.280)  (554.025)
304                    Qw =                                    (39)      (134)
305                    Qg =                               (165.074)  (563.561)
306                            Ql =                        342.322  1.168.687
307 ***********************************************************
308
309            CALCULATION OF GAS TRANSMISIVITY FOR ITS OWN RADIATION
310
311            sg        -(1-TRgg1)*Ems*As      -0.1535
312               2.00 -(TRgg1-TRgg2)*Fsw*pw    -0.0018
313               3 00 -(TRgg2-TRgg3)*Fww*Fs    -0.0001
314               4.00 -(TRgg2-TRgg3)*Fws*Fs    -0.0000
315                                             -0.1555
316
317            wg        -(1-TRgg1)*Emw*Aw      -0.5836
318               2 00 -(TRgg1-TRgg2)*Fww*pw    -0.0062
319               3.00 -(TRgg2-TRgg3)*Fww*Fw    -0.0004
320               4.00 -(TRgg2-TRgg3)*Fws*Fs    -0.0001
321               5.00 -(TRgg2-TRgg3)*Fws*Fw    -0 0001
322               6.00 -(TRgg1-TRgg2)*Fws*ps    -0 0018
323                                             -0.5922
324
325
326            Ig     1 0-(1-TRgg1)*Emf*At      -0 5684
327               2 00 -(TRgg1-TRgg2)*ps*Fls    -0 0044
328               3 00 -(TRgg2-TRgg3)*ps*pw*    -0 0003
329               4 00 -(TRgg1-TRgg2)*pw*Flw    -0 0154
330               5 00 -(TRgg2-TRgg3)*pw*ps*    -0 0003
```

```
K              L            M          N          O          P         Q
----------------------------------------------------------------------------
|          1000 00       0 09    1000 00       0 09    1000 00  ********
|          1500 00       0 11    1500 00       0 11    1500 00  ********
|          2000 00       0 10    2000 00       0 10    2000.00  ********
|                   ---------- ---------   --------   --------  -------
|                      500.00                  0 42    5000.00  ********
|                                                 Y          X      X#2
|
|               L=       0 18                 Y=Emg        X=T      X^2
|          2500 00       0 09    2500.00       0 09    2500.00  ********
|          3000 00       0 07    3000 00       0 07    3000.00  ********
|          3500 00       0 06    3500.00       0 06    3500 00  ********
|          4000 00       0 05    4000 00       0 05    4000.00  ********
|                   ---------- ---------   --------   --------  -------
|                      500.00                  0 26   13000.00  ********
|                                                 Y          X      X#2
*************************************************************************
| BASIS   GAS ENTHALPY                                       SEC &
| -------------------                            Sim      FEED COMBST
|          FEED LB/HR   1335 00 CO2 LB/HR =    569 19              569 19
|               % H2O    10.10%  O2 LB/HR     448 72      389 33   59 40
|   Cp BTU/LB*F  DRY    0.2600   N2 LB/HR    3452 25     1289 02 2163 23
|                             LBS H2O/HR      381 96      151 62  230 34
|      F/D FILL RATIO    10.00 TOTAL LB/HR   4852 12     1829 96 3022 15
| % EXCESS AIR SEC. =   65 58% MOLES H2O       21 22        8 42   12 80
| AIR DENSITY, LB/FT3   0 0811  MOLES GAS     171 47       66 63  104 85
|  MOLAR VOL  FT3/MOL   355 65  MOL % H2O   0 1238 CO2 LBm/HR   12 94
|            Tair. F     70 00  MOL % CO2   0 0754 O2 LBm/HR      1 86
| HEAT OF VAPOR. BTU/L 1060 00                     N2 LBm/HR    77.26
|  hcvws BTU/FT^2*F =     8.80                    H2O LBm/HR    12.80
|                     T ABM.K=    294 40
| BASIS : SOIL ENTHALPY
| ------------------------------
| SOIL DRY BASIS, LB2/HR         1200.17
|         BTU/HR*F =              312.04
|        DEL Ts. K =              731.91
|
|        QS BTU/HR =    554025               Qs1 BTU/HR=       0
|  BTU/HR UP TO 212 =    47431
| DEL Hv H2O. BTU/HR =  142925
|  BTU/HR ABOVE 212 =   363669
|        DEL Ts. F =      1317
|        DEL Ts. C =    731.91
|        DEL TS. K =    731.91
|
| HEAT LOSS CALC FOR FLAME HMB
| ------------------------------
|  -Qs SOLID.BTU/HR =   554025 <====INCLUDES HEAT OF VAPOR. OF WATER IN
|   -Qw WALL,BTU/HR =      134
|    -Qg GAS.BTU/HR =   563561
| SHELL LOSS BTU/HR =    50967
| Ql1 OR Ql2 BTU/HR =        0 <==== ENTHALPY CALC FOR RECIRC GAS
| ------------------------------            OR FEED & AIR PREHEATED
|   TOTAL MM BTU/HR =   1 1687
|
| ---------------------------------------------------------------------
```

```
         R        S        T          U        V         W         X         Y          Z        AA      AB     AC    AD   AE   AF   AG   AH   AI   AJ
-- ----------------------------------------------------------------------------------------------------------------------------------------------------
276 ********************    93 89    93885 44    1 00      C =    2500 00     C =    6500 00   1000 00   0 10   0 09
277 ********************   158 36   237543 23    1 00      D =       0 11     D =       0 16   1500 00   0 10   0 11
278 ********************   209 75   419492 92    1 00      E = ***********    E = ***********  2000 00   0 11   0 10
279 --------  --------  --------    --------  --------                                       2500 00   0 09   0 09
280 ********************   521 88   780862.43    4 00      a =       0 15     a =       0 21   3000 00   0 07   0 07
281      X#3      X#4       XY       X#2Y        N        b =      -0 00     b =      -0 00   3500 00   0 06   0 06
282                                                       c =       0 00     c =       0 00   4000 00   0 05   0 05
283      X^3      X^4       XY       X^2Y        N                                            2811 90   0 08
284 ********************   221 15   552881.40    1.00
285 ********************   213 97   641904.21    1.00
286 ********************   200.91   703180.23    1.00
287 ********************   181.80   727207.93    1.00
288 --------  --------  --------    --------  --------
289 ********************   817.83  2625181.77    4.00
290      X#3      X#4       XY       X#2Y        N
291 ***************************************************************************************************************************************************
292         | COMBUSTION GAS ENTHALPY CALC.                                  |
293         |    Tf =     2351 90              Tg IN =     2251 90           |
294         |                  Cp        Tg                   Tg             |
295         |            BTU/LB*F    BTU/HR               BTU/HR             |
296         |                           OUT                   IN             |
297         |       CO2    0.2816   367.314   0 2797     348 998             |
298         |        O2    0.2667    36.307   0 2656      34 585             |
299         |        N2    0 2730 1.353.287   0.2718   1.288.998             |
300         |       H2O    0.5327   525.387   0.5287     511.112             |
301         |                   -----------           -----------            |
302         |                     2.282.295             2.183.693            |
303         | DEL H GAS. BTU/HR =     98602                                  |
304         |            WATTS        28882  Cp IN =      0 5442             |
305         |   BTU/F =              986.02 Cp OUT =      0 5444             |
306         | DEL Tg. K =            317.53                                  |
307         |                  A          B       C                          |
308         |                                                                |
309         |                0 20      0.00   -0 00          CO2             |
310         |                0.24      0.00   -0.00           O2             |
311         |                0.24      0.00   -0.00           N2             |
312         |                0.44      0.00   -0.00          H2O             |
313         | -------------------------------------------------------        |
314         | FEED GAS ENTHALPY CALC USED                                    |
315         |    Tg =     1181.97              Tg IN =       69 92           |
316         |                  Cp        Tg                   Tg             |
317         |            BTU/LB*F    BTU/HR               BTU/HR             |
318         |                           OUT                   IN             |
319     ERR       CO2    0.2508           0   0.2029           0             |
320  284.23        O2    0.2533     110.658   0.2386         921             |
321  290.89        N2    0.2593     374.967   0 2447       3.130             |
322 1605 29       H2O    0.4860     243.392   0.4411     161.379             |
323         |                   -----------           -----------            |
324         |                       729.017               165.430            |
325         | DEL H GAS. BTU/HR =    563587                                  |
326         |            WATTS       165081  Cp IN =      0 3551             |
327         |   BTU/F =              506.80 Cp OUT =      9 1130             |      Y=BTU/LB     X=PL
328         | DEL Tg. K =            617.78                                  |      2088.000   400 00
329         |                  A          B       C                          |      2467.000   500 00
330 ----------                                                 -----------        2942 000   600 00
```

```
        AL       AM      AN       AO       AP    AQ       AR       AS    AT       AU       AV      AW        AX        AY        AZ       BA       BB       BC    BD
-- -------------------------------------------------------------------------------------------------------------------------------------------------------------------
276  1000 00   0 12 1000.00   0 12  1000 00 ******************************************   1 00   C =  2500 00   C =  6500 00  1000 00   0 13   0 12   I
277  1500 00   0 14 1500 00   0 14  1500 00 ******************************************   1 00   D =     0 13   D =     0 22  1500 00   0 13   0 14   I
278  2000 00   0 14 2000.00   0 14  2000 00 ******************************************   1 00   E = *********  E = *********  2000 00   0 14   0 14   I
279           --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                           2500 00   0 13   0 13   I
280                               0 54  5000.00 ******************************************   4 00   a =     0 17   a =     0 24  3000 00   0 11   0 11   I
281                                  Y        X   X#2      X#3      X#4    XY      X#2Y      N   b =    -0 00   b =    -0 00  3500 00   0 09   0 09   I
282                                                                                             c =     0 00   c =     0 00  4000 00   0 07   0 07   I
283      L=   0.90               Y=Emg      X=T   X^2      X^3      X^4    XY      X^2Y      N                                2587 64   0.12          I
284  2500 00   0 13 2500.00   0 13  2500.00 ******************************************   1 00                                                         I
285  3000 00   0 11 3000.00   0 11  3000.00 ******************************************   1 00                                                         I
286  3500 00   0 09 3500 00   0.09  3500.00 ******************************************   1 00                                                         I
287  4000 00   0 07 4000 00   0 07  4000.00 ******************************************   1 00                                                         I
288           --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                                                      I
289                               0.39 13000.00 ******************************************   4 00                                                         I
290                                  Y        X   X#2      X#3      X#4    XY      X#2Y      N
291 *******************************************************************************************************************************************************************
292
293 H2Ogt3    500.00 1000.00  1500 00  2000 00 ****** 3000 00  3500 00 ******  750 00
294 --------- -------- ------- -------- -------- ----- -------- -------- ----- --------
295 a           0 19    0 14    0 11     0 08  0 06     0 04     0 03  0 02     0 15
296 b           0 14    0 14    0 14     0 13  0 12     0 10     0 06  0 07     0 15
297 c          -0 01   -0.02   -0 01    -0.01 -0 01    -0 01    -0 01 -0 01    -0 02
298           Y=Emg     X=T
299      L=     0.27             Y=Emg      X=T   X^2      X^3      X^4    XY      X^2Y      N   A =     0 00      X=T   Y calc Y act=Eg
300   500 00   0.23  500.00   0.23   500 00 ****************************57517 65   1 00   B =    -0.00   500.00     0 22    0 23
301   750 00   0.19  750 00   0 19   750 00 ******************************************   1.00   C =  4400 00  1000.00     0.18    0 17
302  1000 00   0.17 1000.00   0.17  1000 00 ******************************************   1.00   D =     0.23  1500 00     0 14    0 15
303  1500 00   0.15 1500 00   0 15  1500 00 ******************************************   1 00   E = *********  2000 00     0 11    0.12
304  2000 00   0.12 2000.00   0 12  2000 00 ******************************************   1.00                  2500.00     0 09    0 09
305  2500.00   0.09 2500.00   0.09  2500.00 ******************************************   1.00   a =     0.27  3000 00     0.07    0 07
306  3000 00   0.07 3000.00   0.07  3000.00 ******************************************   1.00   b =    -0.00  3500 00     0 05    0 06
307  3500 00   0 06 3500.00   0.06  3500.00 ******************************************   1.00   c =     0 00  4000.00     0 05    0 04
308  4000 00   0.04 4000.00   0.04  4000 00 ******************************************   1.00                  2811.90     0 08
309           --------- ------- -------- -------- ----- -------- -------- ----- -------- --------
310             500.00            1.11 18750.00 ******************************************   9.00      ABgf3 = (ABCO2+ABH2O)(1-CSO1)
311                                  Y        X   X#2      X#3      X#4    XY      X#2Y      N                 0.1105
312                                                                                                 ABCO2 = ( EmCO2 @ Ts, P*L*Ts/Tg )*(Tg/Ts).65
313                                                                                                            0.06
314 CO2g2     500.00 1000.00  1500 00  2000.00 ****** 3000.00  3500 00 ******                  ABH2O = ( EmH2O @ Ts, P*L*Ts/Tg )*(Tg/Ts).45
315 --------- -------- ------- -------- -------- ----- -------- -------- -----                                0 06
316 a           0.11    0.09    0.10     0.09  0.08     0 06     0 05  0 04
317 b           0.04    0.05    0.05     0.06  0.06     0.06     0 05  0 04                       Tg =      1641.97   pl13 =      0.16
318 c          -0.00   -0.01   -0.01    -0.01 -0.01    -0.01    -0.00 -0.00                         Tg =  2811.90 Csog2 =      0.06              {?}{Down}
319
320           Y=Emg     X=T
321      L=     0.27             Y=Emg      X=T   X^2      X^3      X^4    XY      X^2Y      N   A =     0 00   A =     0 00      X=T   Y calc Y act=Eg
322   500 00   0.12  500 00   0.12   500.00 **********************61.52 30758 37   1.00   B =    -0 00   B =    -0.00   500 00     0.12    0 12
323  1000 00   0.10  000.00   0.10  1000.00 **********************97 69 97693.59   1.00   C =  2500 00   C =  6500.00  1000.00     0.11    0.10
324  1500 00   0.11 1500.00   0.11  1500.00 ******************************************   1.00   D =     0.12   D =     0.17  1500 00     0 10    0.11
325  2000 00   0 11 2000.00   0.11  2000 00 ******************************************   1 00   E = *********  E = *********  2000 00     0 11    0 11
326           --------- ------- -------- -------- ----- -------- -------- ----- -------- --------                           2500 00     0 09    0 09
327             500 00            0.44  5000 00 ******************************************   4 00   a =     0.15   a =     0.22  3000 00     0 08    0 08
328                                  Y        X   X#2      X#3      X#4    XY      X#2Y      N   b =    -0 00   b =    -0 00  3500 00     0 06    0 06
329                                                                                             c =     0.00   c =     0 00  4000 00     0 05    0 05
330      L=     0 27             Y=Emg      X=T   X^2      X^3      X^4    XY      X^2Y      N                                2811 90     0 08
```

```
        A       B        C        D        E        F        G        H        I        J        K              L            M          N          O          P        Q
-- ---------------------------------------------------------------------------------------------------------------------------------------------------------------------------
331             6 00 -(IRgg2-IRgg3)*pw*pw*    -0 0009                                        |
332                                           -0 5697                                        | CROSSECTIONAL AREA OF BED =                                   0 0896
333                                                                                          | = ((D/2)^2)(THIRAD/2-@COS(THIRAD/2)*@SIN(THIRAD/2))
334 IRg11 = (-(Tfg+Img+Isg)-Emg*(Af+ABw*Aw+ABS*AS))/(Emg*(pw*Aw*(Fwf+ABw*Fww+ABS*Fws)+pS*AS*(FSf+ABw*FSw)))   % FILL =                                0 0701
335          =   0 1870                                                                      | SOLID BED VOLUME. m^3 =                                       0 4367
336                                                                                          |              FT^3 =                                          15 4216
337     IRgs11 = (-Isg-ABS*Emg*AS)/(ABS*pw*FwS*Emg*Aw)                                        | CROSECT. AREA OF FREEBOARD. Axf  m^2 =                        1.28
338          =   0 1873                                                                      | FREEBOARD VOLUME. m^3 =                                       6 23
339                                                                                          | -------------------------------------------------------------------------------
340     IRgw11 = (-Iwg-ABw*Emg*Aw)/((pw*Fww*Aw+pS*FSw*AS)*ABw*Emg)         PREHEAT OF FEUL AND AIR    % FEUL USED SECT 1 =      100%                  29-Feb 3. mxair
341          =   0 1869                                                   Tf1 =     2351.90   TOTAL   SECT 1 COMBUSTED  PREHEATED              TOTAL    TOTAL 4. 1/3X(
342                                                                                           LB/HR           LB/HR       LB/HR     BTU/HR  mcp+mxair  mxair
343     IRgf11 = (-Ifg-Af*Emg)/((pw*Fwf*Aw+pS*FSf*AS)*Emg)                FEUL LB/HR =        178 00          178 00       0.00         0     LB/HR    LB/HR
344          =   0 1870                                                   CO2 LB/HR =                                                           569.19     0.00 5. mxair
345                                                                       BURNER O2. LB/HR =   653 37          653 37       0 00         0     448.63   389 23 6. X(mcp
346 ----------------------------------------------------------------------BURNER N2. LB/HR =  2163 23         2163 23       0.00         0    3452.25  1289 02
347                                                                       BURNER H2O. LB/HR=    28 17           28 17       0 00         0     381.96   151.62
348                                                                                  ------------------------------------------------------------------------------9  mxair
349                                                                                  .    3023            3023          0          0       4852     1830 10  mcp+
350
351                                                                       RECICULATION FRAC  =           *mo + X(mcp + mxair)
352                                                                          X =                  0 00 *mo/(mcp + mxair) =      0 000
353
354                                                                       Qf1 TOTAL = (1-%COMB)mo(Tf1-To) + 1/3X(mcp+mxair)(Tf1-Tg1)
355                                                                          Qf1 =          0          0               0
356
357                                                                       Qf2 TOTAL = -(1-%COMB)mo(Tf1-To) + 1/3X(mcp+mxair)(Tf2-Tf1) + 2(1/3X(mcp+mxair)(Tf2-Tg2) + mcp1(Tf2-T
358                                                                          Qf2 =          0          0               0                    0
359                                                                          Qf2 =          0
360
361                                                                       Qf TOTAL  BTU/HR = X(mcp + mxair)*(Tf-Tg) = 3(1/3X(mcp - mxair))
362                                                                          Qf =           0
363
364
365
366                                                                       FEUL BTU/LB =          1695.20
367
368 ---------------------------------------------------------------------------------------------------------------------------------------------------------------------------
369
370     29-Feb 3. TgIHMB COMBUSTION GAS ENTHALPY CALC.  Tgo --> Tg1        4. TgIHMB ENTHALPY CALC. 1/3X(mcp+mxair) Tg2=Tg3 --> Tg1          7. Tg1 COMBUSTION GAS ENTHALPY CALC. : M
371            +Tgo =     69.92              Tg1 =      69.92            Tg2=Tg3 = 1181.97               Tg1 =            69.92             +Tgo =      69.92            Tg1 =
372      TOTAL                  Cp       Tg                   Tg                             Cp        Tg                        Tg     mxair +                Cp        Tg
373      mxair             BTU/LB*F   BTU/HR              BTU/HR 1/3X(mcp+mxair)        BTU/LB*F   BTU/HR                    BTU/HR 1/3X(mcp+mxair)        BTU/LB*F   BTU/HR
374      LB/HR                          OUT                   IN     LB/HR                          OUT                          IN     LB/HR                          OUT
375          0     CO2      0 2029        0   0 2029          0          0     CO2   0 2508         0   0.2029                0          0     CO2     0 2029         0  0.2029
376        389      O2      0 2386      921   0.2386        921          0      O2   0.2533         0   0.2386                0        389      O2     0.2386       921  0.2386
377       1289      N2      0 2447     3130   0.2447      3,130          0      N2   0.2593         0   0.2447                0       1289      N2     0.2447      3130  0.2447
378        152     H20      0 4411   161381   0.4411    161.381          0     H20   0.4860         0   0.4411                0        152     H20     0.4411    161381  0.4411
379 ------------           ---------         ---------------------               -----------         ----------------------------              -----------
380       1830                       165431               165.431          0                          0                          0       1830                      165431
381          DEL H GAS. BTU/HR =          0                           DEL H GAS. BTU/HR           0                                     DEL H GAS. BTU/HR =          0
382                         WATTS         0   Cp IN =     9 1130                      WATTS        0  Cp IN =                 ERR                     WATTS           0 Cp IN =
383          BTU/F =                    ERR   Cp OUT =    9 1130           BTU/F =                 0  Cp OUT =                ERR           BTU/F =                 ERR Cp OUT =
384          DEL Tg. K =                ERR                                DEL Tg. K =           ERR                                    DEL Tg. K =             ERR
385 ---------------------------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
        R        S        T        U        V        W        X        Y        Z        AA       AB       AC       AD       AE       AF       AG       AH       AI       AJ
-- -------------------------------------------------------------------------------------------------------------------------------------------------------------------------
331                  0 20     0 00    -0 00      CO2                         3425 000   700 00
332                  0 24     0 00    -0.00      O2                          3944 000   800 00               ---------
333                  0 24     0 00    -0.00      N2                          7814 000  1500 00
334                  0 44     0.00    -0.00      H20                         --------  --------
335                                                                         22680 000  4500 00
336          AVG  DENSITY OF SOLID BED. LB/FT^3 =   100 00                          Y         X
337          SOLID FEED RATE  FT^3/HR =              13.35
338          RESIDENCE TIME FOR SOLID BED  HR =       1 155
339 -------------------------------------------------------------------------------------------------------------------------------------------------------------------------
340          Tg1-Tgo BTU/HR =          0
341 MCP+MXAIR)Tg1-Tg2 BTU/HR =         0          1. QF1A ENTH CALC   1/3*X(MCP+MXAIR)(TF-Tg)  1/3X=            2  QF2B ENTH CALC  1/3X(MCP+MXAIR)(TF2-TF1)
342          -Qg1 BTU/HR = +           0             +TF =     2351 90    +Tg =     1181 97             TF2 =  2351 90    TF1 =    2351.90 1/3X=       0 00
343                                                                Cp        Tg                      Tg                     Cp          Tg                  Tg
344          Tg2-Tg1 BTU/HR =     563560 1/3X(MCP+MXAIR)      BTU/LB*F   BTU/HR                  BTU/HR 1/3X(MCP+MXAIR)  BTU/LB*F   BTU/HR              BTU/HR
345 +MXAIR)  Tg2-Tg3 BTU/HR =          0     LB/HR                        OUT                      IN     LB/HR                     OUT                 IN
346          -Qg2 BTU/HR = +      563560         0       CO2     0 2816        0     0 7508           0         0     CO2   0.2816       0    0 2816       0
347                                              0        O2     0 2667        0     0 2533           0         0      O2   0.2667       0    0 2667       0
348          Tg2-Tg3 BTU/HR =    -413861         0        N2     0 2730        0     0.2593           0         0      N2   0 2730       0    0. 2730      0
349 X(MCP+MXAI-(Tg3-TF2) BTU/HR =   413867         0       H20     0 5327        0     0 4860           0         0     H20   0. 5327      0    0.5327       0
350                        0 =         6 ---------              ----------          --------------------           -----------       ---------
351                                              0                         0                          0         0                    0                  0
352                                        DEL H GAS. BTU/HR =             0                                          DEL H GAS. BTU/HR     0
353 + ==> Tg +                                           WATTS             0   Cp IN =              ERR                        WATTS         0  Cp IN =    0.0000
354                                             BTU/F =                    0   Cp OUT =             ERR          BTU/F =                   ERR Cp OUT =   0.0000
355 Qg BTU/HR=  -563561                    DEL Tg. K =                   ERR                                  DEL Tg. K =              ERR
356                                    ----------------------------------------------------------------------------------------------------------------
357 TT)                                                       A           B          C                                          A          B         C
358                                                        0 20        0.00      -0 00       CO2                              0.20       0 00     -0 00      CO2
359                                                        0 24        0 00      -0.00        O2                              0 24       0.00     -0.00       O2
360                                                        0 24        0.00      -0 00        N2                              0.24       0.00     -0 00       N2
361                                                        0.44        0 00      -0 00       H20                              0 44       0.00     -0.00      H20
362                                    -------------------------------------------------------------      ------------------------------------------------
363
364
365
366
367
368 -------------------------------------------------------------------------------------------------------------------------------------------------------------------------
369
370 XAIR + 1/3X(MCP+MXAIR)        8  Tg2 COMBUSTION GAS ENTHALPY CALC.:  MXAIR + X(MCP+MXAIR)
371     69.92                        +Tg2 =  1181.97                 TgIHHB =     69.92
372        Tg            MXAIR +                  Cp          Tg                  Tg
373     BTU/HR        X(MCP+MXAIR)           BTU/LB*F      BTU/HR              BTU/HR
374        IN              LB/HR                             OUT                  IN
375         0                  0        CO2    0.2508          0     0 2029        0
376       921                389         O2    0 2533     110631     0 2386      921
377     3.130               1289         N2    0.2593     374967     0 2447     3130
378   161.381                152        H20    0.4860     243394     0.4411  161.381
379 ----------         ----------                    -----------          ----------
380   165.431               1830                          728992              165431
381                         DEL H GAS  BTU/HR =           563560
382       ERR                                WATTS        165073   Cp IN =       ERR
383       ERR                     BTU/F =                    507   Cp OUT =      ERR
384                         DEL Tg. K =                       -0
385 ----------------------------------------------------------------------------------
```

AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
2500 00	0 09	2500 00	0.09	2500.00	********	********	********	********	********	1 00								
3000 00	0 08	3000 00	0 08	3000 00	********	********	********	********	********	1.00								
3500 00	0 06	3500 00	0 06	3500 00	********	********	********	********	********	1 00								
4000 00	0 05	4000 00	0.05	4000.00	********	********	********	********	********	1.00								
	---------	-------	--------	--------	-----	--------	--------	-----	--------	--------								
	500.00		0.28	13000.00	********	********	********	********	********	4.00								
			Y	X	X#2	X#3	X#4	XY	X#2Y	N								

HV FELA OIL													
Y=BTU/LB	X=PL	X^2	X^3	X^4	XY		X^2Y	N	A =	0.00		X=T	Y calc
259	400	********	********	********	********		********	1.00	B =	0.66		400.00	255.57
306	500	********	********	********	********		********	1 00	C =	1964.52		600 00	366 86
365	600	********	********	********	********		********	1 00	D =	-23.01		700 00	475 61
425	700	********	********	********	********		********	1.00	E =	********		800.00	486.43
489	800	********	********	********	********		********	1 00				1500.00	970 02
970	1500	********	********	********	********		********	1.00	a =	57.7904		2351 90	1695.20
--------	--------	-------	--------	--------	--------		--------	-----	b =	0.4531			
2815	4500	********	********	********	********		********	6 00	c =	0 0001		.	
Y	X	X#2	X#3	X#4	XY		X#2Y	N					
							X#2Y	N			SP GR =	0 97	
											LB/FT3 =	60 27	
											LB/GAL =	8 06	

CSO1		PCO2/(PH2O+PCO2) = .35											
Y=CSO	X=PL	X^2	X^3	X^4	XY		X^2Y	N	A =	-0.02	X=T	Y calc	Y act=Cso
0.016	0.10	0.01	0.00	0.00	0.00		0.00	1 00	B =	0.03	0 10	0 02	0.02
0 030	0.25	0.06	0.02	0.00	0.01		0 00	1 00	C =	2.05	0.75	0.05	0 05
0.052	0.75	0.56	0.42	0 32	0 04		0 03	1 00	D =	0.02	1.00	0.06	0 06
0.059	1.00	1.00	1 00	1 00	0 06		0.06	1.00	E =	-0.60	1.50	0 07	0.07
0.065	1.50	2.25	3.38	5.06	0 10		0.15	1.00			2.00	0 07	0.07
0 068	2.00	4.00	8.00	16.00	0 14		0 27	1.00	a =	0.0122		0.01	<==== Cso
--------	--------	-------	--------	--------	--------		--------	-----	b =	0.0660			
0 290	5.60	7.89	12.81	22.38	0 34		0 51	6.00	c =	-0.0193			
Y	X	X#2	X#3	X#4	XY		X#2Y	N					

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
386			A	B	C				A	B	C				A	B	C
387			0.20	0.00	-0.00	CO2			0.20	0.00	-0.00	CO2			0.20	0.00	-0.00
388			0.24	0.00	-0.00	O2			0.24	0.00	-0.00	O2			0.24	0.00	-0.00
389			0.24	0.00	-0.00	N2			0.24	0.00	-0.00	N2			0.24	0.00	-0.00
390			0.44	0.00	-0.00	H2O			0.44	0.00	-0.00	H2O			0.44	0.00	-0.00
391																	
392																	
393		5 Tg2HMB COMBUSTION GAS ENTHALPY CALC Tg1 --> Tg2					6 Tg2HMB ENTHALPY CALC X(mcp+mxair) Tg3 ---> Tg2						9 Tg3HMB COMBUSTION GAS ENTHALPY CALC				
394		Tg1 =	69.92		Tg2 =	1181.97		Tg3 =	1927.46		Tg2 =	1181.97		Tg2 =	1181.97		Tg3 =
395	TOTAL		Cp	Tg		Tg			Cp	Tg		Tg	TOTAL		Cp	Tg	
396	mxair		BTU/LB*F	BTU/HR		BTU/HR X(mcp+mxair)			BTU/LB*F	BTU/HR		BTU/HR	mxair		BTU/LB*F	BTU/HR	
397	LB/HR			OUT		IN	LB/HR			OUT		IN	LB/HR			OUT	
398	0	CO2	0.2029	0	0.2508	0	0	CO2	0.2728	0	0.2508	0	0	CO2	0.2508	0	0.2728
399	389	O2	0.2386	921	0.2533	110.631	0	O2	0.2621	0	0.2533	0	389	O2	0.2533	110631	0.2621
400	1289	N2	0.2447	3130	0.2593	374.967	0	N2	0.2682	0	0.2593	0	1289	N2	0.2593	374967	0.2682
401	152	H2O	0.4411	161381	0.4860	243.394	0	H2O	0.5158	0	0.4860	0	152	H2O	0.4860	243394	0.5158
402																	
403	1830			165431		728.992	0			0		0	1830			728992	
404		DEL H GAS BTU/HR =		-563560				DEL H GAS BTU/HR		0				DEL H GAS BTU/HR =		-413861	
405			WATTS	-165073	Cp IN =	ERR			WATTS	0	Cp IN =	ERR			WATTS	-121225	Cp IN =
406		BTU/F =		507	Cp OUT =	ERR		BTU/F =		0	Cp OUT =	ERR		BTU/F =		555	Cp OUT =
407		DEL Tg. K =		0				DEL Tg K =		ERR				DEL Tg. K =		-0	
408																	
409			A	B	C				A	B	C				A	B	C
410			0.20	0.00	-0.00	CO2			0.20	0.00	-0.00	CO2			0.20	0.00	-0.00
411			0.24	0.00	-0.00	O2			0.24	0.00	-0.00	O2			0.24	0.00	-0.00
412			0.24	0.00	-0.00	N2			0.24	0.00	-0.00	N2			0.24	0.00	-0.00
413			0.44	0.00	-0.00	H2O			0.44	0.00	-0.00	H2O			0.44	0.00	-0.00
414																	

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
386					A	B	C												
387	CO2				0 20	0 00	-0 00	CO2											
388	O2				0 24	0 00	-0 00	O2											
389	N2				0 24	0 00	-0 00	N2											
390	H2O				0.44	0 00	-0 00	H2O											
391	----------		----------	----------	----------	----------	----------	----------											
392																			
393	T92 --> Tg3		10.Tg3HHB ENTHALPY CALC MCP + X(MCP+Mxair) Tf2 ---> Tg3						11 Tf2 HHB ENTHALPY CALC MCP1 Tf1 ---> Tf2										
394	1927 46			Tf2 =	2351.90		Tg3 =	1927 46		Tf2 =	2351.90		Tf1 =	2351 90					
395	Tg		MCP +		Cp	Tg		Tg	MCP +		Cp	Tg		Tg					
396	BTU/HR		X(MCP+Mxair)		BTU/LB*F	BTU/HR		BTU/HR	X(MCP+Mxa ir)		BTU/LB*F	BTU/HR		BTU/HR					
397	IN		LB/HR			OUT		IN	LB/HR			OUT		IN					
398	0		569	CO2	0 2816	367314	0.2728	289 929	569	CO2	0 2816	367314	0 2816	367.314					
399	190 517		59	O2	0.2667	36309	0 2621	29.075	59	O2	0 2667	36309	0 2667	36.309					
400	645 563		2163	N2	0 2730	1353288	0 2682	1 083 382	2163	N2	0 2730	1353288	0 2730	1.353.288					
401	306 773		230	H2O	0 5327	525391	0 5156	466 048	230	H2O	0 5327	525391	0 5327	525.391					
402	----------		----------			----------		----------	----------			----------		----------					
403	1 142 853		3022			2282301		1868433	3022			2282301		2282301					
404					DEL H GAS. BTU/HR =	413867					DEL H GAS. BTU/HR =	0							
405	ERR				WATTS	121227	Cp IN =	ERR			WATTS	0	Cp IN =	ERR					
406	ERR			BTU/F =		975	Cp OUT =	ERR		BTU/F =		ERR	Cp OUT =	ERR					
407				DEL Tg, K =		0				DEL Tg K =		ERR							
408	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------					
409					A	B	C				A	B	C						
410	CO2				0 20	0 00	-0.00	CO2			0 20	0 00	-0.00	CO2					
411	O2				0 24	0 00	-0 00	O2			0.24	0.00	-0.00	O2					
412	N2				0 24	0 00	-0 00	N2			0.24	0 00	-0 00	N2					
413	H2O				0.44	0 00	-0.00	H2O			0.44	0 00	-0.00	H2O					
414	----------		----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------					

FKILN.WK1 ** Range Report **
Page 1
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

* General Information - Lotus 123 Spreadsheet *

Source Path	C:\LOTUS\S\FKILN.WK1
Active Range	A1..BO436
Iteration Count	1
Recalculation	manual
Recalc Order	natural

* Principal Window *	cursor at E60
Global Col Width	9
Global Format	(F2)

Column Widths individually specified as follows:

A	B	C	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AE	AH	AK	AN	AO	AT
13	9	12	11	11	11	9	11	10	20	11	11	11	10	8	10	10	10	11	9	11	11	10	12	12	9	8	11	9	1	8	6	6

* Named Ranges *

1	A34..O53
10G	I393..Y414
11G	Z393..AE408
1G	V341
2	J33..O52
2G	AB341
3	AC34..AJ53
3G	A370
4	A1..T28
4A	U2..AJ28
4G	G370
50	V39
50A	V49
50S	V48
5G	A393
6G	G393
7G	M370
8	U33..AJ54
8G	T370
9	M34..A185
9G	M393
ABF	F74
ABG1	C93
ABG11	C84
ABG2	C94
ABG3	C95
ABGF1	A52
ABGF2	A53
ABGF3	A54
ABGS1	A02
ABGS2	A04
ABGS3	A56
ABGW1	A03
ABGW2	A55
ABGW3	A57
ABS	F72
ABW	F73
ACO	R39
ACO2	R39
AF	I59
AG	I62
AH20	R43

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

AHBA	R46
AHCL	R44
AHF	R47
AN	R42
AN2	R42
AO	R41
AREA3	I65
AS	I60
ASH	I66
ASO	R45
AW	I61
BACK	R23
BCO	S39
BH2O	S43
BHBA	S46
BHCL	S44
BHF	S47
BN	S42
BO	S41
BSO	S45
C	A55
CALC	G122
CC	AM18..AM26
CCO	T39
CH2O	T43
CHBA	T46
CHCL	T44
CHF	T47
CN	T42
CO	T41
CONST	A55..J109
CSO	T45
CSO1	AL357
D	I74
DATE	F129
DELH	AL357
DELP	D52
DELS	G122
E	A109..E128
EC	A370..L385
ECA	M370..Y385
ECB	A393..L408
ECF	M392..Y408
EF	F82
EG	F81
EN	AL1..BO8
ENF	F78
ENG	AQ1
ENG2	AS1
ENG3	AU1
ENG	F76
ENSH	F75
ENT1	AL1..BO339
ENT2	K55..AC291
ENW	F77
EN	N311..AD332
ES	F79
EW	F80

FKILN.WK1 ** Range Report **
Page 3
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

F	AL357
FD	I81
FF	B286
FFS	F66
FFW	F65
FG	B243
FL	AL357
FLA	I340..U362
FLA1	V341..AG356
FLF	I58
FQ	AL357
FS	B158
FSF	F67
FSW	F62
FW	B200
FWF	F68
FWS	F63
FWW	F64
G	K56
GF	B281
GG	B236
GS	B154
GW	B195
H	L292..W340
HCDWSH	F95
HCVGS	C100
HCVGW	C101
HCVSHA	C102
HCVWS	C99
HL	L320
HRSHA	F97
HS	L306
I	A34
INS1	I83
INS2	I84
KK1	I86
KK2	I87
KKK1	A129
KKK2	A129
L	I75
LL	I76
LM	F90
LM2	F91
LM3	F92
MOLTOT	F84
PAUX	D51
PCO2	F85
PG	F71
PH2O	F86
PH2O	F86
PL1	C105
PL2	C106
PL3	C107
PLF1	J91
PLF2	J92
PLF3	J93
PS	F69
PT	D50

FKILNLWK1 FLAME REGION MODELED AS ONE SECTION

PW	F70
PIS	P35
PISB	Q35
PISC	Q36
Q1A	N349
Q1B	Y352
Q2C	AE352
QCHCV	F104
QF	F299
QF1	J355
QF2	J359
QFF	F297
QFG	F249
QFS	F165
QFW	F211
QG	F254
QGF	F284
QGG	F241
QGS	F156
QGW	F198
QS	F170
QSF	F266
QSG	F226
QSHR	F106
QSOL	BD318
QSS	F144
QSW	F181
QW	F217
QWCO	F102
QWF	F279
QWG	F234
QWS	F152
QWW	F193
R	A129
RAD	A129..G307
RC	N352
RF	I72
RR1	I68
RR2	I69
RR3	I70
RSH	I71
S	BD318
SF	B259..C262
SG	B222..C225
SHELL	I85
SIGMA	F83
SS	B139..C143
SW	B175..C180
T	A309..F344
TA	C98
TC	D340
TF	C59
TFG	E332
TG	C64
TGRID	B335
THI	I78
THIRAD	I79
TITLE	G122

FKILNLWK1 ** Range Report **
Page 5
FKILNLWK1 FLAME REGION MODELED AS ONE SECTION

TRGI1	B335
TRGF1	C86
TRGF11	B344
TRGF2	C87
TRGF3	C88
TRGG1	C90
TRGG2	C91
TRGG3	C92
TRGS1	C75
TRGS11	B338
TRGS2	C76
TRGS3	C77
TRGW1	C78
TRGW11	B341
TRGW2	C79
TRGW3	C80
TS	C62
TSG	E315
TSH	C63
TSHOCK	F39
TW	C61
TWG	E323
W	I63
WF	B260
WG	B228
WS	B146
WW	B183
ZAIR	C97
Z	A261
\A	G130
\C	J115
\E	G128
\F	G116
\H	G119
\P	G122
\R	G125
\S	O125
\T	G111
\Z	BD318

Print range	Z393..AE408
Print style	formatted
Global Protection	not enabled
Setup string	\015
Margins	Left Right Top Bottom PageLen
	0 240 0 0 66
Label Prefix	" (double quote)

* Graphs *

(Current) line graph
no data ranges specified

** End of range report **

```
FKILN.WK1  ** Range ! [A34..D53] +VAL **
Page 6
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     !   -A-    !                                   -B-                                         !
34   !          !                                                                               !
35   !          !"PRIMARY                                                                       !
36   !"NAME:    !"AUX FUEL                                                                      !
37   !"% C      !87.21                                                                          !
38   !"% H2     !12.62                                                                          !
39   !"% O2     !0                                                                              !
40   !"% N2     !0                                                                              !
41   !"% WATER  !0                                                                              !
42   !"% CL     !0                                                                              !
43   !"% S      !0.17                                                                           !
44   !"% BR     !0                                                                              !
45   !"% F      !0                                                                              !
46   !"% SALT   !0                                                                              !
47   !"% ASH    !0                                                                              !
48   !          !" --------                                                                     !
49   !"TOTAL    !@SUM(B36..B48) (100)                                                           !
50   !"LB/HR    !" ----                                                                         !
51   !"BTU/LB   !(((B37/100)*(1/12))+((B38/100)*(0.5/2))+((B39/100)*(-1/32))+((B40/100)*(1/14))+((B43/100)*(1/32)))*184003.25 (19187.5139039)!
52   !"TEMP F   !60                                                                             !
53   !"BTU/LB F !0.5                                                                            !
```

```
FKILN.WK1  ** Range 1 [A34..D53] *VAL **
Page 7
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |                                    -C-                                                      |      -D-       |
34   |"INPUT TEMPLATE 1                                                                            |                |
35   |"--------                                                                                    |"BURNER WASTES----||
36   |"WASTE 1                                                                                     |"WASTE 2        |
37   |0                                                                                            |0               |
38   |0                                                                                            |0               |
39   |0                                                                                            |0               |
40   |0                                                                                            |0               |
41   |0                                                                                            |0               |
42   |0                                                                                            |0               |
43   |0                                                                                            |0               |
44   |0                                                                                            |0               |
45   |0                                                                                            |0               |
46   |0                                                                                            |0               |
47   |0                                                                                            |0               |
48   |" --------                                                                                   |" --------      |
49   |@SUM(C36..C48) (0)                                                                           |@SUM(D36..D48) (0) |
50   |0                                                                                            |0               |
51   |(((C37/100)*(1/12))+((C38/100)*(0.5/2))+((C39/100)*(-1/32))+((C40/100)*(1/14))+((C43/100)*(1/32)))*184003.25 (0)|0 |
52   |60                                                                                           |60              |
53   |0.5                                                                                          |0.5             |
```

FKILN.WK1 ** Range 1 (A34..O53) *VAL ** (07-13-88 13:31)
Page 8
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

```
    |                         -E-                          |                        -F-                          |
34  |'PRIMARY CHAMBER WASTE DATA                           |                                                     |
35  |                                                      |"|--------                                           |
36  |"WASTE3                                               |"WASTE 4                                             |
37  |0                                                     |0                                                    |
38  |0                                                     |0                                                    |
39  |0                                                     |0                                                    |
40  |0                                                     |0                                                    |
41  |0                                                     |0                                                    |
42  |0                                                     |0                                                    |
43  |0                                                     |0                                                    |
44  |0                                                     |0                                                    |
45  |0                                                     |0                                                    |
46  |0                                                     |0                                                    |
47  |0                                                     |0                                                    |
48  |" --------                                            |"|--------                                           |
49  |@SUM(E36..E48) (0)                                    |@SUM(F36..F48) (0)                                   |
50  |+1*0.05 (0)                                           |0                                                    |
51  |(((E37/100)*(1/12))+((E38/100)*(0.5/2))+((E39/100)*(-1/32))+((E40/100)*(1/14))+((E43/100)*(1/32)))*184003.25 (0)|(((F37/100)*(1/12))+((F38/100)*(0.5/2))+((F39/100)*(-1/32))+((F40/100)*(1/14))+((F43/100)*(1/32)))*184003.25 (0)|
52  |60                                                    |60                                                   |
53  |0.5                                                   |0.5                                                  |
```

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-G-	-H-	-J-	-K-	-L-
34					
35	"CHAMBER WASTES---|		"% EXCESS AIR FOR FUELS TO BURNER		
36	"WASTE 5	"WASTE 6	"% EXCESS AIR FOR WASTES TO CHAMBER		
37	0	0	"RADIATION LOSS (MM BTU/HR)		
38	0	0	"AIR TEMP F		
39	0	0	"AIR HUMIDITY (LB/LB DRY AIR)		
40	0	0	"% ASH IN EXIT		
41	0	0	"% SALT IN EXIT		
42	0	0			
43	0	0	"PYROLYSIS (1 = YES, 0 = NO)		
44	0	0	"HEAT OF PYROLYSIS BTU/LB		
45	0	0	"AVG MOL WEIGHT OF PYROLYSIS PRODUCTS		
46	0	0	"% FIXED CARBON IN ASH		
47	0	0	"SPECIFIC HEAT OF ASH (BTU/LB F)		
48	" --------	" -------|	"DESIRED ASH DISCHARGE TEMPERATURE F		
49	@SUM(G36..G48) (0)	@SUM(H36..H48) (0)			
50	+I*0.95 (0)	0	"DESIRED OR "GUESS" TEMPERATURE F		
51	(((G37/100)*(1/12))+((G38/100)*(0.5/2))+((G39/100)*(-1/32))+((G40/100)*(1/14))+((G43/100)*(1/32)))*10*(03.25 (0)	0	"LBS/HR AUX FUEL		
52	60	60	"HEAT IN =	+C27+H27 (3.452154976912)	" HEAT OUT =
53	0.5	0.5			

```
FKILN.WK1  ** Range : [A34..U53] *VAL **
age 10
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
    |                   -N-                    |              -O-                               |     -P-      |       -Q-          |
34  |                                          |                                                |              |                    |
35  |"========)                                |+XAIR (10)                                      |              |                    |
36  |"========)                                |0                                               |              |                    |
37  |"========)                                |+M328 (1.16868687348G)                          |" (=+Qf orQg  |                    |
38  |"========)                                |+TA*1.8-460 (69.92)                             |              |                    |
39  |"========)                                |0.01                                            |              |                    |
40  |"========)                                |0                                               |              |                    |
41  |"========)                                |0                                               |              |                    |
42  |                                          |                                                |              |                    |
43  |"========)                                |0                                               |              |                    |
44  |"========)                                |360                                             |              |                    |
45  |"========)                                |50                                              |              |                    |
46  |"========)                                |0                                               |              |                    |
47  |"========)                                |0.26                                            |              |                    |
48  |"========)                                |0                                               |"(- USED IF INPUT|                  |
49  |                                          |                                                |              |                    |
50  |"========)                                |@IF(AF=0,(TG-273)*1.8+32,(+TF-273)*1.8+32) (2352.50116633|" (=+Tf |         |                    |
51  |"========)                                |+C55 (178)                                      |521.16        |                    |
52  |+A127+R27+O37+@IF(O43=0,0,O44*A18/1000000) (3.451876479279)|"*  |                   |"DELTA H =    |+K52-N52 (0.00027849763?)|
53  |                                          |                                                |              |                    |
```

```
FKILN.WK1  ** Range 4 [A1..I28] +VAL **
age 11
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |                  -A-                       |B-|                 -C-                                        |          D-            |E |          -F
1    |"PRIMARY BURNER AND CHAMBER MASS AND HEAT BALANCE RESULTS|  |                                            |                        |  |
2    |--------------------------------------------|\-|--------------------------------------------------------|------------------------|\-|-----------------------------
3    |                                            |"||"        (1)                                             |                        |"||"        (2)                    |
4    |                                            |"||"TOTAL WASTE + FUEL                                      |                        |" |"AUX FUEL TO BURNER             |
5    |                                            |"||"LB/HR                                                   |"LB-M/HR                |"||"LB/HR                         |
6    |--------------------------------------------|"||-------------------------------------------------------|" --------               |"||-----------------------------|
7    |"C                                          |"||+F7+I7+L7 (155.2338)                                    |+C7/12 (12.93615)       |"||+B37*PAUX/100 (155.2338)      |
8    |"H2                                         |"||+F8+I8+L8 (22.4636)                                     |+C8/2 (11.2318)         |"||+B38*PAUX/100 (22.4636)       |
9    |"O2                                         |"||+F9+I9+L9 (0)                                           |+C9/32 (0)              |"||+B39*PAUX/100 (0)             |
10   |"N2                                         |"||+F10+I10+L10 (0)                                        |+C10/28 (0)             |"||+B40*PAUX/100 (0)             |
11   |"WATER                                      |"||+F11+I11+L11 (0)                                        |+C11/18 (0)             |"||+B41*PAUX/100 (0)             |
12   |"CL                                         |"||+F12+I12+L12 (0)                                        |+C12/35.5 (0)           |"||+B42*PAUX/100 (0)             |
13   |"S.                                         |"||+F13+I13+L13 (0.3026)                                   |+C13/32 (0.00945625)    |"||+B43*PAUX/100 (0.3026)        |
14   |"BR                                         |"||+F14+I14+L14 (0)                                        |+C14/79.9 (0)           |"||+B44*PAUX/100 (0)             |
15   |"F                                          |"||+F15+I15+L15 (0)                                        |+C15/19 (0)             |"||+B45*PAUX/100 (0)             |
16   |"SALT                                       |"||+F16+I16+L16 (0)                                        |"----                   |"||+B46*PAUX/100 (0)             |
17   |"ASH                                        |"||+F17+I17+L17 (0)                                        |"----                   |"||+B47*PAUX/100 (0)             |
18   |                                            |"||" --------                                              |" --------              |"||" --------                    |
19   |"TOTAL                                      |"||@SUM(C5..C18) (178)                                     |@SUM(D5..D18) (24.17740625)|"||@SUM(F5..F18) (178)       |
20   |--------------------------------------------|\-|--------------------------------------------------------|------------------------|\-|-----------------------------|
21   |"SCFM                                       |"||                                                        |                        |"||                              |
22   |"ACFM                                       |"||                                                        |                        |"||                              |
23   |"TEMP F                                     |"||((C24*1000000)/(B53*B50+C53*C50+D53*D50+E53*E50+F53*F50+G53*I+H53*H50))+60 (ERR)|  |"||+B52 (60)                  |
24   |"ENTHALPY                                   |"||+L24+I24+F24 (0)                                        |                        |"||(B53*B50*(B52-60))/1000000 (0) |
25   |"HEAT REL                                   |"||+F25+I25+L25 (3.415377474895)                           |                        |"||+B51*PAUX/1000000 (3.415377474895)|
26   |                                            |"||" --------                                              |                        |"||" --------                    |
27   |"MM BTU/HR                                  |"||@SUM(C24..C26) (3.415377474895)                         |                        |"||@SUM(F24..F26) (3.415377474895) |
28   |--------------------------------------------|\-|--------------------------------------------------------|------------------------|\-|-----------------------------|
```

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

```
   |         -G-          |H-|                      -I-                             |     -J-      |K-|                      -L-                          |     -M-      |N-|
1  |                      | |                                                       |              | |                                                    |              | |
2  |----------------------|\-|-------------------------------------------------------|--------------|\-|----------------------------------------------------|--------------|\-|
3  |                      |*||*        (3)                                          |              |*||*        (4)                                     |              |*||
4  |                      |*||* WASTE TO BURNER                                     |              |*||* WASTE TO CHAMBER                               |              |*||
5  |*LB-M/HR              |*||*LB/HR                                                |*LB-M/HR      |*||*LB/HR                                           |*LB-M/HR      |*||
6  |* -------             |*||------------------------------------------------------|* -------     |*||---------------------------------------------------|* -------     |*||
7  |+F7/12 (12.93615)     |*||(C37*$C$50+D37*$D$50+E37*$E$50)/100 (0)               |+I7/12 (0)    |*||(F37*$F$50+G37*(1+H37*$H$50)/100 (0)               |+L7/12 (0)    |*||
8  |+F8/2 (11.2318)       |*||(C38*$C$50+D38*$D$50+E38*$E$50)/100 (0)               |+I8/2 (0)     |*||(F38*$F$50+G38*(1+H38*$H$50)/100 (0)               |+L8/2 (0)     |*||
9  |+F9/32 (0)            |*||(C39*$C$50+D39*$D$50+E39*$E$50)/100 (0)               |+I9/32 (0)    |*||(F39*$F$50+G39*(1+H39*$H$50)/100 (0)               |+L9/32 (0)    |*||
10 |+F10/28 (0)           |*||(C40*$C$50+D40*$D$50+E40*$E$50)/100 (0)               |+I10/28 (0)   |*||(F40*$F$50+G40*(1+H40*$H$50)/100 (0)               |+L10/28 (0)   |*||
11 |+F11/18 (0)           |*||(C41*$C$50+D41*$D$50+E41*$E$50)/100 (0)               |+I11/18 (0)   |*||(F41*$F$50+G41*(1+H41*$H$50)/100 (0)               |+L11/18 (0)   |*||
12 |+F12/35.5 (0)         |*||(C42*$C$50+D42*$D$50+E42*$E$50)/100 (0)               |+I12/35.5 (0) |*||(F42*$F$50+G42*(1+H42*$H$50)/100 (0)               |+L12/35.5 (0) |*||
13 |+F13/32 (0.0079A5625) |*||(C43*$C$50+D43*$D$50+E43*$E$50)/100 (0)               |+I13/32 (0)   |*||(F43*$F$50+G43*(1+H43*$H$50)/100 (0)               |+L13/32 (0)   |*||
14 |+F14/79.9 (0)         |*||(C44*$C$50+D44*$D$50+E44*$E$50)/100 (0)               |+I14/79.9 (0) |*||(F44*$F$50+G44*(1+H44*$H$50)/100 (0)               |+L14/79.9 (0) |*||
15 |+F15/19 (0)           |*||(C45*$C$50+D45*$D$50+E45*$E$50)/100 (0)               |+I15/19 (0)   |*||(F45*$F$50+G45*(1+H45*$H$50)/100 (0)               |+L15/19 (0)   |*||
16 |*----                 |*||(C46*$C$50+D46*$D$50+E46*$E$50)/100 (0)               |*----         |*||(F46*$F$50+G46*(1+H46*$H$50)/100 (0)               |*----         |*||
17 |*----                 |*||(C47*$C$50+D47*$D$50+E47*$E$50)/100 (0)               |*----         |*||(F47*$F$50+G47*(1+H47*$H$50)/100 (0)               |*----         |*||
18 |* --------            |*||* -------                                             |* -------     |*||* --------                                         |* --------    |*||
19 |@SUM(G5..G18) (24.17740625)|*||@SUM(I5..I18) (0)                                |@SUM(J5..J18) (0)|*||@SUM(L5..L18) (0)                               |@SUM(M5..M18) (0)|*||
20 |----------------------|\-|-------------------------------------------------------|--------------|\-|----------------------------------------------------|--------------|\-|
21 |                      |*||                                                      |              |*||                                                  |              |*||
22 |                      |*||                                                      |              |*||                                                  |              |*||
23 |                      |*||((I24*1000000)/(C53*C50+D53*D50+E53*E50))*60 (ERR)     |              |*||((L24*1000000)/(F53*F50+G53*I+H53*H50))*60 (ERR)  |              |*||
24 |                      |*||(C53*C50*(C52-60)+D53*D50*(D52-60)+E53*E50*(E52-60))/1000000 (0)|      |*||(F53*F50*(F52-60)+G53*I*(G52-60)+H53*H50*(H52-60))/1000000 (0)|   |*||
25 |                      |*||(C50*C51+D50*D51+E50*E51)/1000000 (0)                  |              |*||@IF(O43=0,(F50*F51+I*G51+H50*H51)/1000000,0) (0) |              |*||
26 |                      |*||* --------                                            |              |*||* --------                                         |              |*||
27 |                      |*||@SUM(I24..I26) (0)                                    |              |*||@SUM(L24..L26) (0)                                |              |*||
28 |----------------------|\-|-------------------------------------------------------|--------------|\-|----------------------------------------------------|--------------|\-|
```

```
FKILN.WK1  ** Range * [A1..T28] *VAL **
age 13
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
    |                                   -O-                                       |     -P-        |O-|         -R-               |     -S-       ||-|
1   |                                                                             |                | |                            |               | |
2   |-----------------------------------------------------------------------------|----------------|\-|----------------------------|---------------|\-|
3   |"        (5)                                                                 |                |"||"        (6)               |               |"||
4   |"PYROLSIS PRODUCTS                                                           |                |"||" SOLIDS OUT BOTTOM          |               |"||
5   |"LB/HR                                                                       |"LB-M/HR        |"||"LB/HR                       |"LB-M/HR       |"||
6   |-----------------------------------------------------------------------------|" -------       |"||----------------------------|" --------     |"||
7   |@IF(@D$43=0,0,+C7-F7-J7-R7) (0)                                              |+O7/12 (0)      |"||+100.1 (0)                  |+R7/12 (0)     |"||
8   |@IF(@D$43=0,0,L8) (0)                                                        |+O8/2 (0)       |"||0                           |+R8/2 (0)      |"||
9   |@IF(@D$43=0,0,L9) (0)                                                        |+O9/32 (0)      |"||0                           |+R9/32 (0)     |"||
10  |@IF(@D$43=0,0,L10) (0)                                                       |+O10/28 (0)     |"||0                           |+R10/28 (0)    |"||
11  |@IF(@D$43=0,0,L11) (0)                                                       |+O11/18 (0)     |"||0                           |+R11/18 (0)    |"||
12  |@IF(@D$43=0,0,L12) (0)                                                       |+O12/35.5 (0)   |"||0                           |+R12/35.5 (0)  |"||
13  |@IF(@D$43=0,0,L13) (0)                                                       |+O13/32 (0)     |"||0                           |+R13/32 (0)    |"||
14  |@IF(@D$43=0,0,L14) (0)                                                       |+O14/79.9 (0)   |"||0                           |+R14/79.9 (0)  |"||
15  |@IF(@D$43=0,0,L15) (0)                                                       |+O15/19 (0)     |"||0                           |+R15/19 (0)    |"||
16  |@IF(@D$43=0,0,L16*@D$41/100) (0)                                             |"----           |"||+C16-C16*@D$41/100 (0)      |"----          |"||
17  |@IF(@D$43=0,0,L17*@D$40/100) (0)                                             |"----           |"||+C17-C17*@D$40/100 (0)      |"----          |"||
18  |" --------                                                                   |" --------      |"||" --------                   |" --------     |"||
19  |@SUM(O5..O18) (0)                                                            |@SUM(P5..P18) (0)|"||@SUM(R5..R18) (0)          |@SUM(S5..S18) (0)|"||
20  |-----------------------------------------------------------------------------|----------------|\-|----------------------------|---------------|\-|
21  |+AJ8*10.73*520/(14.7*60) (0)                                                 |                |"||                           |               |"||
22  |+AJ8*10.73*(O23+460)/(14.7*60) (0)                                           |                |"||                           |               |"||
23  |+PT (2352.501166339)                                                         |                |"||@IF(D48>0,D48,PT) (2352.501166339)|         |"||
24  |(((O19-O16-O17)*(AH2O+BH2O*(O23-60)+CH2O*(O23-60)^2))+((O16+O17)*O47))*(O23-60)/1000000 (0)|  |"||+R19*D47*(BACK-60)/1000000 (0)|         |"||
25  |0                                                                            |                |"||0                           |               |"||
26  |" --------                                                                   |                |"||" --------                   |               |"||
27  |@SUM(O24..O26) (0)                                                           |                |"||@SUM(R24..R26) (0)          |               |"||
28  |-----------------------------------------------------------------------------|----------------|\-|----------------------------|---------------|\-|
```

```
FKILN.WK1  ** Range 4A (U2..AJ28) *VAL **
age 14
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |  -U-    |V-|                 -W-                  |           -X-             |V-|                 -Z-                    |
2    |---------|\-|--------------------------------------|---------------------------|\-|----------------------------------------|
3    |         |*||*        (7)                          |                           |*||*        (8)                           |
4    |         |*||*     TOTAL AIR                       |                           |*||*   AIR TO BURNER                      |
5    |         |*||*LB/HR                                |*LB-M/HR                   |*||*LB/HR                                 |
6    |---------|*||--------------------------------------|* --------                 |*||----------------------------------------|
7    |*CO2     |*||+X7*44 (0)                            |+AD7+AA7 (0)               |*||+AA7*44 (0)                            |
8    |*PYRO GAS|*||+X8*$D$45 (0)                         |+AD8+AA8 (0)               |*||+AA8*$D$45 (0)                         |
9    |*O2      |*||+X9*32 (653.36502)                    |+AD9+AA9 (20.417656875)    |*||+AA9*32 (653.36502)                    |
10   |*N2      |*||+X10*28 (2163.228694836)              |+AD10+AA10 (77.25816767274)|*||+AA10*28 (2163.228694836)              |
11   |*WATER   |*||+X11*18 (28.1659371483 6)             |+AD11+AA11 (1.56477428602) |*||+$U$39*(Z9+Z10) (28.16593714836)       |
12   |*HCL     |*||+X12*36.5 (0)                         |+AD12+AA12 (0)             |*||+AA12*36.5 (0)                         |
13   |*SO2     |*||+X13*64 (0)                           |+AD13+AA13 (0)             |*||+AA13*64 (0)                           |
14   |*HBR     |*||+X14*80.9 (0)                         |+AD14+AA14 (0)             |*||+AA14*80.9 (0)                         |
15   |*HF      |*||+X15*20 (0)                           |+AD15+AA15 (0)             |*||+AA15*20 (0)                           |
16   |*SALT    |*||*----                                 |*----                      |*||*----                                  |
17   |*ASH     |*||*----                                 |*----                      |*||*----                                  |
18   |         |*||* --------                            |* --------                 |*||* --------                             |
19   |*TOTAL   |*||@SUM(W5..W18) (2844.759651985)        |@SUM(X5..X18) (99.24059843376)|*||@SUM(Z5..Z18) (2844.759651985)      |
20   |---------|\-|--------------------------------------|---------------------------|\-|----------------------------------------|
21   |*SCFM    |*||+X19*10.73*520/(14.7*60) (627.8036794251) |                       |*||+AA19*10.73*520/(14.7*60) (627.8036794251) |
22   |*ACFM    |*||+X19*10.73*(W23+460)/(14.7*60) (639.780241924 8)|                 |*||+AA19*10.73*(Z23+460)/(14.7*60) (639.7802419248)|
23   |*TEMP F  |*||+O38 (69.92)                          |                           |*||+O38 (69.92)                           |
24   |*ENTHALPY|*||@SUM(W39..W49)/1000000 (0.036777502016)|                          |*||@SUM(X39..X49)/1000000 (0.036777502016)|
25   |*HEAT REL|*||0                                     |                           |*||0                                      |
26   |         |*||* --------                            |                           |*||* --------                             |
27   |*MM BTU/HR|*||@SUM(W24..W25) (0.036777502016)      |                           |*||@SUM(Z24..Z25) (0.036777502016)        |
28   |---------|\-|--------------------------------------|---------------------------|\-|----------------------------------------|
```

231

FKILN.WK1 ** Range 4A (U2..AJ28) *VAL **

age 15

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	AA	AB	AC	AD	AE
2					
3			' (9)		
4			' AIR TO CHAMBER		
5	"LB-M/HR		"LB/HR	"LB-M/HR	
6	' -------			' ------	
7	0		+AD7*44 (0)	0	
8	0		+AD8*40845 (0)	0	
9	(((G7+J7+((G8+J8-0.5*(G12+G14+G15+J12+J14+J15))/2)+G13+J13)-(G9+J9))*(1+PISB/100)) (20.417656875)		+AD9*32 (0)	@IF(D43=0,((M7+((M8-0.5*(M12+M14+M15))/2)+M13-M9)*(1+PISC/100)),0) (0)	
10	+AA9*3.78389 (77.25816767274)		+AD10*28 (0)	@IF(D43=0,AD9*3.78389,0) (0)	
11	+Z11/18 (1.56477428602)		+AD11*39*(AC9+AC10) (0)	+AC11/18 (0)	
12	0		+AD12*36.5 (0)	0	
13	0		+AD13*64 (0)	0	
14	0		+AD14*80.9 (0)	0	
15	0		+AD15*20 (0)	0	
16	'----		'---	'----	
17	'---		'----	'---	
18	' --------		' --------	' --------	
19	@SUM(AA5..AA18) (99.2405983376)		@SUM(AC5..AC18) (0)	@SUM(AD5..AD18) (0)	
20					
21			+AD19*10.73*520/(14.7*60) (0)		
22			+AD19*10.73*(AC23+460)/(14.7*60) (0)		
23			+D38 (69.92)		
24			@SUM(Y39..Y49)/1000000 (0)		
25			0		
26			' --------		
27			@SUM(AC24..AC25) (0)		
28					

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-AF-	-AG-	AH	-AI-	-AJ-
2	----------	----------	\-	----------	----------
3	' (10)		'|'	(11)	
4	'COMBUSTION PRODUCTS		'|'	TOTAL OFF-GAS	
5	'LB/HR	'LB-M/HR	'|'	LB/HR	'LB-M/HR
6	----------	' --------	'|	----------	' --------
7	+AG7*44 (569.1906)	+D7-P7-S7 (12.93615)	'|	+AJ7*44 (569.1906)	+AG7 (12.93615)
8	+AG8*$D$45 (0)	0	'|	+D19-D16-D17 (0)	+AI8/$D$45 (0)
9	+AG9*32 (59.39682)	+D9*X9-P9-AG7-AG13-((D8-P8)/2-0.5*(AG12+AG14+AG15)/2) (1.856150625)	'|	+AJ9*32 (59.39682)	+AG9 (1.856150625)
10	+AG10*28 (2163.22869 4836)	+D10-P10*X10 (77.25816767274)	'|	+AJ10*28 (2163.22869 4836)	+AG10 (77.25816767274)
11	+AG11*18 (230.3383371483)	+D11-P11*X11+(D8-P8)-((AG12+AG14+AG15)/2) (12.79657428602)	'|	+AJ11*18 (230.3383371483)	+AG11 (12.79657428602)
12	+AG12*36.5 (0)	+D12-P12 (0)	'|	+AJ12*36.5 (0)	+AG12 (0)
13	+AG13*64 (0.6052)	+D13-P13 (0.0094 5625)	'|	+AJ13*64 (0.6052)	+AG13 (0.0094 5625)
14	+AG14*80.9 (0)	+D14-P14 (0)	'|	+AJ14*80.9 (0)	+AG14 (0)
15	+AG15*20 (0)	+D15-P15 (0)	'|	+AJ15*20 (0)	+AG15 (0)
16	@IF($D$43=0,C16*$D$41/100,(C16-L16)*$D$41/100) (0)	'----	'|	+D16+AF16 (0)	'----
17	@IF($D$43=0,C17*$D$40/100,(C17-L17)*$D$40/100) (0)	'----	'|	+D17+AF17 (0)	'----
18	' --------	' --------	'|'	--------	' --------
19	@SUM(AF5..AF18) (3022.759651985)	@SUM(AG5..AG18) (104.8564988337)	'|	@SUM(AI5..AI18) (3022.759651985)	@SUM(AJ5..AJ18) (104.8564988337)
20	----------	----------	\-	----------	----------
21	+AG19*10.73*520/(14.7*60) (663.3302957969)		'|	+AJ19*10.73*520/(14.7*60) (663.3302957969)	
22	+AG19*10.73*(AF23+460)/(14.7*60) (3587.725443456)		'|	+AJ19*10.73*(AI23+460)/(14.7*60) (3587.725443456)	
23	+PT (2352.501166339)		'|	+PT (2352.501166339)	
24	@SUM(Z39..Z49)/1000000 (2.283189605792)		'|	@SUM(AA39..AA49)/1000000 (2.283189605792)	
25	0		'|	0	
26	' --------		'|'	--------	
27	@SUM(AF24..AF25) (2.283189605792)		'|	@SUM(AI24..AI25) (2.283189605792)	
28	----------	----------	\-	----------	----------

233

```
FKILN.WK1  ** Range B [U33..AJ54] +VAL **
age 17
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |   -U-   |      -V-      |                               -W-                                         |                               -X-                                         |
33   |"TEMPLATE 8|               |"COMPONENT HEAT BALANCE  BTU/HR                                            |                                                                           |
34   |-----------|---------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
35   |           |^(5)           |^(7)                                                                       |^(8)                                                                       |
36   |           |"PYROLYS       |"TOTAL                                                                     |"AIR TO                                                                    |
37   |           |"PRODUCTS      |"AIR                                                                       |"BURNER                                                                    |
38   |-----------|" --------     |" --------                                                                 |" --------                                                                 |
39   |"CO2       |0              |(W7*(ACO+BCO*(W$23-60)+CCO*(W$23-60)^2))*(W$23-60)  (0)                    |(Z7*(ACO+BCO*(Z$23-60)+CCO*(Z$23-60)^2))*(Z$23-60)  (0)                    |
40   |"PYRO GAS  |+D24*1000000 (0)|(W8*($R$40+$S$40*(W$23-60)+$T$40*(W$23-60)^2))*(W$23-60)  (0)            |(Z8*($R$40+$S$40*(Z$23-60)+$T$40*(Z$23-60)^2))*(Z$23-60)  (0)            |
41   |"O2        |0              |(W9*(AO+BO*(W$23-60)+CO*(W$23-60)^2))*(W$23-60)  (1546.419348195)          |(Z9*(AO+BO*(Z$23-60)+CO*(Z$23-60)^2))*(Z$23-60)  (1546.419348195)          |
42   |"N2        |0              |(W10*(AN+BN*(W$23-60)+CN*(W$23-60)^2))*(W$23-60)  (5251.940245635)         |(Z10*(AN+BN*(Z$23-60)+CN*(Z$23-60)^2))*(Z$23-60)  (5251.940245635)         |
43   |"WATER     |0              |(W11*1060)+((W11*(AH2O+BH2O*(W$23-60)+CH2O*(W$23-60)^2)))*(W$23-60)  (29979.14242283)|(Z11*1060)+((Z11*(AH2O+BH2O*(Z$23-60)+CH2O*(Z$23-60)^2)))*(Z$23-60)  (29979.14242283)|
44   |"HCL       |0              |(W12*(AHCL+BHCL*(W$23-60)+CHCL*(W$23-60)^2))*(W$23-60)  (0)                |(Z12*(AHCL+BHCL*(Z$23-60)+CHCL*(Z$23-60)^2))*(Z$23-60)  (0)                |
45   |"SO2       |0              |(W13*(ASO+BSO*(W$23-60)+CSO*(W$23-60)^2))*(W$23-60)  (0)                   |(Z13*(ASO+BSO*(Z$23-60)+CSO*(Z$23-60)^2))*(Z$23-60))  (0)                  |
46   |"HBR       |0              |(W14*(AHBR+BHBR*(W$23-60)+CHBR*(W$23-60)^2))*(W$23-60)  (0)                |(Z14*(AHBR+BHBR*(Z$23-60)+CHBR*(Z$23-60)^2))*(Z$23-60)  (0)                |
47   |"HF        |0              |(W15*(AHF+BHF*(W$23-60)+CHF*(W$23-60)^2))*(W$23-60)  (0)                   |(Z15*(AHF+BHF*(Z$23-60)+CHF*(Z$23-60)^2))*(Z$23-60)  (0)                   |
48   |"SALT      |"INCL          |(W16*($D$47*(W$23-60)))*(W$23-60)  (0)                                     |(Z16*($D$47*(Z$23-60)))*(Z$23-60)  (0)                                     |
49   |"ASH       |"INCL          |(W17*($D$47*(W$23-60)))*(W$23-60)  (0)                                     |(Z17*($D$47*(Z$23-60)))*(Z$23-60)  (0)                                     |
50   |           |" --------     |" --------                                                                 |" --------                                                                 |
51   |"TOTAL     |@SUM(V38..V50)  (0)|@SUM(W38..W50)  (36777.50201666)                                       |@SUM(X38..X50)  (36777.50201666)                                           |
52   |           |               |                                                                           |                                                                           |
53   |           |               |                                                                           |+X43/Z11  (1064.375819093)                                                 |
54   |***********|***************|***************************************************************************|***************************************************************************|
```

```
FKILN.WK1  ** Range B (U33..AJ54) +VAL **
age 18
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
    |                              -Y-                                    |                              -Z-                                         |
33  |                                                                     |                                                                          |
34  |---------------------------------------------------------------------|--------------------------------------------------------------------------|
35  |^(9)                                                                 |^(10)                                                                     |
36  |"AIR TO                                                              |"COMBUST                                                                  |
37  |"CHAMBER                                                             |"PRODUCTS                                                                 |
38  |" --------                                                           |" --------                                                                |
39  |(AC7*(ACO+BCO*(AC$23-60)+CCO*(AC$23-60)^2))*(AC$23-60)  (0)          |(AF7*(ACO+BCO*(AF$23-60)+CCO*(AF$23-60)^2))*(AF$23-60)  (367424.3364215)   |
40  |(AC8*($R40+$S40*(AC$23-60)+$T40*(AC$23-60)^2))*(AC$23-60)  (0)       |(AF8*($R40+$S40*(AF$23-60)+$T40*(AF$23-60)^2))*(AF$23-60)  (0)            |
41  |(AC9*(AO+BO*(AC$23-60)+CO*(AC$23-60)^2))*(AC$23-60)  (0)             |(AF9*(AO+BO*(AF$23-60)+CO*(AF$23-60)^2))*(AF$23-60)  (36316.95065798)     |
42  |(AC10*(AN+BN*(AC$23-60)+CN*(AC$23-60)^2))*(AC$23-60)  (0)            |(AF10*(AN+BN*(AF$23-60)+CN*(AF$23-60)^2))*(AF$23-60)  (1353673.764995)    |
43  |(AC11*1060)+((AC11*(AH2O+BH2O*(AC$23-60)+CH2O*(AC$23-60)^2)))*(AC$23-60)  (0)|(AF11*1060)+((AF11*(AH2O+BH2O*(AF$23-60)+CH2O*(AF$23-60)^2)))*(AF$23-60)  (525472.9758147)|
44  |(AC12*(AHCL+BHCL*(AC$23-60)+CHCL*(AC$23-60)^2))*(AC$23-60)  (0)      |(AF12*(AHCL+BHCL*(AF$23-60)+CHCL*(AF$23-60)^2))*(AF$23-60)  (0)           |
45  |(AC13*(ASO+BSO*(AC$23-60)+CSO*(AC$23-60)^2))*(AC$23-60)  (0)         |(AF13*(ASO+BSO*(AF$23-60)+CSO*(AF$23-60)^2))*(AF$23-60)  (301.5779030761)  |
46  |(AC14*(AHBR+BHBR*(AC$23-60)+CHBR*(AC$23-60)^2))*(AC$23-60)  (0)      |(AF14*(AHBR+BHBR*(AF$23-60)+CHBR*(AF$23-60)^2))*(AF$23-60)  (0)           |
47  |(AC15*(AHF+BHF*(AC$23-60)+CHF*(AC$23-60)^2))*(AC$23-60)  (0)         |(AF15*(AHF+BHF*(AF$23-60)+CHF*(AF$23-60)^2))*(AF$23-60)  (0)              |
48  |(AC16*($O$47*(AC$23-60)))*(AC$23-60)  (0)                            |(AF16*($O$47*(AF$23-60)))  (0)                                            |
49  |(AC17*($O$47*(AC$23-60)))*(AC$23-60)  (0)                            |(AF17*($O$47*(AF$23-60)))  (0)                                            |
50  |" --------                                                           |" --------                                                                |
51  |@SUM(Y38..Y50)  (0)                                                  |@SUM(Z38..Z50)  (2283189.605792)                                          |
52  |                                                                     |                                                                          |
53  |                                                                     |                                                                          |
54  |*********************************************************************|**************************************************************************|
```

FKILN.WK1 FLAME REGION MODELLED AS ONE SECTION

```
    |                            -AA-                                        |                -AB-                       |              -AC-                 |        -AD-          |
33  |                                                                        |                                           |                                   |                      |
34  |------------------------------------------------------------------------|                                           |'PRIMARY COMBUSTION CHAMBER SUMMARY|                      |
35  |^(11)                                                                   |                                           |'TEMP =                            |+P1 (2352.5)11(66339) |
36  |'TOTAL OFF                                                              |                                           |-----------------------------------|----------------------|
37  |'GAS                                                                    |                                           |'AUX FUEL                          |                      |
38  |' --------                                                              |                                           |'WASTE TO BURNER                   |                      |
39  |(AI17*(ACO+BCO*(AI$23-60)+CCO*(AI$23-60)^2))*(AI$23-60) (367424.3364215)  |@IF(AI17=0,0,+AA39/AI7) (645.5207384337)     |'WASTE TO CHAMBER                  |                      |
40  |(AI8*($R40+$S40*(AI$23-60)+$T40*(AI$23-60)^2))*(AI$23-60) (0)             |@IF(AI8=0,0,+AA40/AI8) (0)                  |'STOIC AIR TO BURNER               |                      |
41  |(AI9*(AO+BO*(AI$23-60)+CO*(AI$23-60)^2))*(AI$23-60) (36316.95065798)      |@IF(AI9=0,0,+AA41/AI9) (611.4292188024)      |'XS AIR TO BURNER                  |                      |
42  |(AI10*(AN+BN*(AI$23-60)+CN*(AI$23-60)^2))*(AI$23-60) (1353673.764995)     |@IF(AI10=0,0,+AA42/AI10) (625.7654441374)    |'STOIC AIR TO CHAMBER              |                      |
43  |(AI11*1060)+((AI11*(AH2O+BH2O*(AI$23-60)+CH2O*(AI$23-60)^2)))*(AI$23-60) (525472.9758147)|@IF(AI11=0,0,+AA43/AI11) (2281.309235449)|'XS AIR TO CHAMBER           |                      |
44  |(AI12*(AHCL+BHCL*(AI$23-60)+CHCL*(AI$23-60)^2))*(AI$23-60) (0)            |@IF(AI12=0,0,+AA44/AI12) (0)                |'AIR HUMIDITY                      |                      |
45  |(AI13*(ASO+BSO*(AI$23-60)+CSO*(AI$23-60)^2))*(AI$23-60) (301.5779030761)  |@IF(AI13=0,0,+AA45/AI13) (498.3111418971)    |'PYRO PRODUCTS                     |                      |
46  |(AI14*(AHBR+BHBR*(AI$23-60)+CHBR*(AI$23-60)^2))*(AI$23-60) (0)            |@IF(AI14=0,0,+AA46/AI14) (0)                |'COMBUSTION GAS                    |                      |
47  |(AI15*(AHF+BHF*(AI$23-60)+CHF*(AI$23-60)^2))*(AI$23-60) (0)               |@IF(AI15=0,0,+AA47/AI15) (0)                |'SOLIDS OUT BOTTOM                 |                      |
48  |(AI16*($O$47*(AI$23-60))) (0)                                             |@IF(AI16=0,0,+AA48/AI16) (0)                |'HEAT OF PYROLYSIS                 |                      |
49  |(AI17*($O$47*(AI$23-60))) (0)                                             |@IF(AI17=0,0,+AA49/AI17) (0)                |'HEAT LOSS                         |                      |
50  |' --------                                                              |                                           |                                   |                      |
51  |@SUM(AA38..AA50) (2283189.605792)                                       |                                           |'TOTAL                             |                      |
52  |                                                                        |                                           |'AIR SCFM:                         |                      |
53  |                                                                        |                                           |'% XS AIR OVERALL                  |'OVERALL =            |
54  |************************************************************************|*******************************************|***********************************|**********************|
```

FKILN.WK1 ** Range B [U33..AJ54] +VAL **
age 20
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-AE-	-AF-	-AG-	-AH-
33				
34		" LBS/HR		
35	'F	^IN	^OUT	
36		--	" --------	
37		+F19 (178)	" ----	
38		+I19 (0)	" ----	
39		+L19 (0)	" ----	
40		(G7+J7+G13+J13-G9-J9+(G8+J8)/2-0.5*(G12+G14+G15+J12+J14+J15)/2)*137.94892 (2560.53974076)	" ----	
41		+AF40*PISB/100 (256.053974076)	" ----	
42		@IF(D43=0,(M7+M13+M8/2-0.5*(M12+M14+M15)/2)*137.94892,0) (0)	" ----	
43		+AF42*PISC/100 (0)	" ----	
44		+W11 (28.16593714836)	" ----	
45		0	+O19 (0)	
46		0	+AF19 (3022.759651985)	
47		0	+R19 (0)	
48		" ----	" ----	
49		" ----	" ----	
50		--	" --------	
51		@SUM(AF36..AF50) (3022.759651985)	@SUM(AG36..AG50) (3022.759651985)	
52	^BURNER =	+Z21 (627.803679425)	^CHAMBER =	+AC21 (0)
53	@IF((AF40+AF42)=0,0,(AF41+AF43)/(AF40+AF42)) (0.1)		"OFF-GAS ADTN =	
54	**	**	********************************	**********

```
FKILN.WK1  ** Range B [U33..AJ54] +VAL **
age 21
FKILNLWK1 FLAME REGION MODELED AS ONE SECTION
     |                                  -AI-                       |              -AJ-              |
33   |                                                             |                                |
34   |"    MM BTU/HR                                               |                                |
35   |^IN                                                          |^OUT                            |
36   |-------------------------------------------------------------|" --------                      |
37   |+F27 (3.415377474895)                                        |" ----                          |
38   |+I27 (0)                                                     |" ----                          |
39   |+L27 (0)                                                     |" ----                          |
40   |@IF(AF40=0,0,(X51-X43)*(AF40/(AF40+AF41))/1000000) (0.006180326903)|" ----                    |
41   |@IF(AF41=0,0,+(X51-X43)*(AF41/(AF41+AF40))/1000000) (0.00061803263)|" ----                    |
42   |@IF(AF42=0,0,+(Y51-Y43)*(AF42/(AF42+AF43))/1000000) (0)       |" ----                          |
43   |@IF(AF43=0,0,+(Y51-Y43)*(AF43/(AF43+AF42))/1000000) (0)       |" ----                          |
44   |+W43/1000000 (0.0299791424221                                |" ----                          |
45   |0                                                            |+O27 (0)                        |
46   |0                                                            |+AF27 (2.283189605792)          |
47   |0                                                            |+R27 (0)                        |
48   |" ----                                                       |+X31 (0)                        |
49   |" ----                                                       |+O37 (1.168686873486)          |
50   |-------------------------------------------------------------|" --------                      |
51   |@SUM(AI36..AI50) (3.452154976912)                            |@SUM(AJ36..AJ50) (3.451876479279)|
52   |"OVERALL =                                                   |+AF52+AH52 (627.803679425)      |
53   |+AI22 (3587.725443456)                                       |                                |
54   |*************************************************************|********************************|
```

	-A-	-B-	-C-	-D-	-E-
55	'PAUX LB/HR =		178*(+A340) (178)		'% FEUL COMB. SEC' 1 =
56	'HEAT IN =	+K52 (3.452154976912)	'HEAT OUT =		+M52 (3.451876479273)
57	--	--	--		'Tf, F
58		'T, F	'T, K	'T NEW	+TF*1.8-460 (2351.901166339)
59	'Tf=	+TF*1.8-460 (2351.901166339)	+D59 (1562.167314633)	+TF+H56*10 (1562.170099609)	+Tf*1.8-460 (2351.901166339)
60	'Tg=	+TG*1.8-460 (1181.966459613)	+D60 (912.2035886741)	+TG-(G59+D69)/1000 (912.2047144462)	+F60+E60*0.0005 11927.464600175)
61	'Tw=	+TW*1.8-460 (2127.636437027)	+D61 (1437.575798348)	+TW-C68*0.0001 11437.5797202)	'IMo =
62	'Ts=	+TS*1.8-460 (1377.601452302)	+D62 (1020.889695723)	+TS-(TS-C72)*0.2 (1020.894584541)	'Fsw =
63	'Tsh=	+TSH*1.8-460 1353.4076297979)	+C64 (451.89312766551		'Fws =
64	'Tsh check =		+TSHCCK (451.6935591416)	'	'Fmw =
65	1350	((+A65-32)/1.8)+272.2 (448.8666666666)		'	'Ffw =
66	'Qs + Qw + Qg + Qf =		+QG+QW+QS+QF (14928.79651721)	+C66*3.414 (50966.91130977)	'Ffs =
67	'Qs = --------	--	+QS (-162280.1989821)	'	'Fsf =
68	'Qw = --------	--	+QW (-39.21852042004)	'	'Fwf =
69	'Qg = --------	--	+QG (-165073.6587062)	+C69*3.414 (-563561.470823)	'ps =
70	'Qf =	--	+QF (342321.872726)	'	'pw =
71	'Qwcd =		+QWCD (14927.61128344)	'	'pg =
72	'DEL Ts, K =	+N310 (731.9141398062)	+B72+289 (1020.914159806)	'	'ABs =
73	'DEL Tg, K =	@IF(AF=0,+QG*3.414/((+U325+U327)*1.81,-QG*3.414/(P383*1.81)) (ERR)	@IF(+J55)0,(+C74+460)/1.8+B73,+TA+B73) (ERR)	'	'ABw =
74	'DEL Tg, F =	+B73*1.8 (ERR)	+B60-B74 (ERR)	'	'ABf =
75	'TRgs1 =		1-ABGS1 (0.7839506968)	'	'EAsh =
76	'TRgs2 =		1-ABGS2 (0.741371890936)	'	'EAs =
77	'TRgs3 =		1-ABGS3 (0.7022442072441)	'	'EAw =
78	'TRgw1 =		1-ABGW1 (0.851731600141)	'	'EAf =
79	'TRgw2 =		1-ABGW2 (0.802473016424)	'	'Es =
80	'TRgw3 =		1-ABGW3 (0.7623931436241)	'	'Ew =
81				'	'Eg =
82	'EMg =		+EMG (0.2320588369231)	'	'Ef =
83	'TRg11=(ABg2+ABg3*(Fwm*pw+Fws*ps))/ABg1	(B94+B95*(E64*E70+E63*E69))/B93 (ERR)	+TGA11 (0.1869770068971)	'	'sigma =
84	'ABg11 =		1-TGA11 (0.8130229931021)	'	'Moles total =
85				'	'Pco2 =
86	'TRgf1 =		1-ABGF1 (0.9072040056921)	'	'PH2O =
87	'TRgf2 =		1-ABGF2 (0.8983901150441)	'	'PCO2 + PH2O =
88	'TRgf3 =		1-ABGF3 (0.8894861787921)	'	
89				'	'LM=.66*D*(1-FD)
90	'TRgg1 =		1-EMG (0.767941163076)	'	'Lm, m =
91	'TRgg2 =		1-+EMG2 (0.727439798465)	'	'2Lm ,m =
92	'TRgg3 =		1-+EMG3 (0.6897309416021)	'	'3Lm ,m =
93	'ABg1 = 1 - TRgg1		1-TRGG1 (0.2320588369231)	'	
94	'ABg2 = TRgg1 - TRgg2 =		+TRGG1-TRGG2 (0.040501364611)	'	'hcdwsh =
95	'ABg3 = TRgg2 - TRgg3 =		+TRGG2-TRGG3 (0.03770885686631)	'	' =
96	**	**	**	'	'hrsha =
97	'% excess air =		10	'	' =
98	'Ta =	(+TA-273)*1.8+32 (70.52)	294.4	'	'Tsh check =
99	'hcvws =		150	'	
100	'hcvgs =		150	'	'Qwcd = Qshcv + Qshr
101	'hcvgw =		120	'	'Qwcd =
102	'hcvsha =		10	'	
103	'hrsha =		+HRSHA (8.615937694191)	'	'Qshcv =
104				'	
105	'(PH2O+Pco2)*Lm =		(PH2O+PCO2)*LM (0.1532357028971)	'	'Qshr =
106	'(PH2O+Pco2)*Lm2 =		(PH2O+PCO2)*LM2 (0.306471405794)	'	
107	'(PH2O+Pco2)*Lm3 =		(PH2O+PCO2)*LM3 (0.4597071086911)	'	'Qshcv+Qshr =
108	--	--	--	-------------------------	--
109	--	--	--	@INT(@NOW) (32202)	--

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-F-	-G-	-H-	-I-
55		+H340 (1)	@INT(@NOW) (32202)	"1No =
56		"DELTA H =	+DELP (0.000278497632)	
57	' Tg, F	"DEL Hg, BTU/HR	------------------------	
58	+TA*1.8-460 (69.92)	+U340+U341 (0)		0.8
59	+TG*1.8-460 (1181.966459613)	+U344+U345 (563560.3450351)	'Af =	+FLF*I64 (2.4494369601 5)
60	+EG0 (1927.461489724)	+U348+U349 (6.220902404747)	'As =	+W*LL (0.826928261808)
61	0	'	'Aw =	(@PI-THIRAD/2)*D*LL (3.14344409886)
62	1-FSF (0.341757502292)	'	'Ag =	+AW+AS+AF (6.419809320819)
63	(@SIN(+THIRAD/2)/(@PI-THIRAD/2))*FSW (0.085904235113)	@IF(+J59=0,0,((2*J72*J76)/J60)*G62) (0)	'Ws, m =	+D*@SIN(THIRAD/2) (0.8484796447 86)
64	1-FWS-FWF (0.304035158825)	@IF(+J59=0,0,((2*J72*J76)/J61)*G61) (0)	'Af' =	(@PI*RF*2)*LL (3.061796200188)
65	(2*@PI-THIRAD)/(2*@PI) (0.777777777777)	'	'Area3 =	2*@PI*RR3*LL (4.974806466066)
66	1-FFW (0.222222222222)	'	'Ash =	2*@PI*RSH*LL (5.091460901293)
67	@IF(+AF=0,0,((AF)/AS)*FFS) (0.658242497707)	'		
68	@IF(+AF=0,0,((AF)/AW)*FFW) (0.606060606060)	'	'rr1, m =	+D/2 (0.66)
69	1-ABS (0.2)	'	'rr2, m =	+RR1+INS1*0.0254 (0.7616)
70	1-REW (0.2)	'	'rr3, m =	+RR2+INS2*0.0254 (0.8124)
71	0	'	'rsh, m =	+RR3+SHELL*0.0254 (0.83145)
72	+EMS (0.8)	'	'rf, m =	0.5
73	+EMW (0.8)	'		
74	+EMF (1)	'	'D, m =	1.32
75	0.7	'	'L, m =	4.873
76	0.8	'	'LL, m =	+L/5 (0.9746)
77	0.8	'		
78	1	'	'Thi =	180
79	+SIGMA*TS*TS*TS*TS (61588.31752571)	'	'THIrad =	(+THI/180)*@PI (3.1415926535)
80	+SIGMA*TW*TW*TW*TW (242162.0419891)	'	'0.95*G028*(1-B029)	
81	+SIGMA*TG*TG*TG*TG (35259.98819782)	'	'F/D =	0.5*(1-@COS(THIRAD/2)) (0.116977778441)
82	+SIGMA*TF^4 (337670.5972801)	'		
83	56.7/1E9 (5.67E-8)	'	'ins1, in. =	14
84	+AJ19 (104.8564988337)	'	'ins2, in. =	2
85	+D302 (0.075441246375)	'	'shell, in =	0.75
86	+D301 (0.123756099113)	'	'kk1, BTU/hr*ft**2*F/in =	5.5
87	+PCO2+PH2O (0.199191345488)	'	'kk2, BTU/hr*ft**2*F/in =	2
88		'	'km1, W/m**2*K/m =	+KK1/6.94 (0.792507204611)
89		'	'km2, W/m**2*K/m =	+KK2/6.94 (0.288184438041)
90	0.66*D*(1-FD) (0.769288959422)	'		
91	+LM*2 (1.538577918845)	'(PH2O+Pco2)*(rr1-rf) =		
92	+LM*3 (2.307866878267)	'(PH2O+Pco2)*(rr1-rf)*2 =		
93		'(PH2O+Pco2)*(rr1-rf)*3 =		
94	' 1/[(2*@PI*rr3)*[(rr2-rr1)/(@pi*km1*(rr1+rr2))+(rr3-rr2)/(@pi*km2*(rr3+rr2))]]			
95	1/((2*@PI*RR3)*((RR2-RR1)/(@PI*I88*(RR1+RR2))+(RR3-RR2)/(@PI*I89*(RR3+RR2)))) (3.044226807653)	'		
96	' sigma*EMsh*(Tsh*Tsh*Tsh*Tsh-Ta*Ta*Ta*Ta)/(Tsh-Ta)			
97	+SIGMA*EMSH*(TSH*TSH*TSH*TSH-TA^4)/(TSH-TA) (8.615937694191)	'		
98	' (hcdwsh*Area3*Tw+Ash*hcvsha*Ta+Ash*hrsha*Ta)/(hcdwsh*Area3+Ash*hcvsha+Ash*hrsha)			
99	(HCDWSH*AREA3*TW+ASH*HCVSHA*TA+ASH*HRSHA*TA)/(HCDWSH*AREA3+ASH*HCVSHA+ASH*HRSHA) (451.8935591416)	'		
100				
101	'Area3*hcdwsh*(Tw-Tsh)			
102	+AREA3*HCDWSH*(TW-TSH) (14927.61128344)	'		
103	'Ash*hcvsha*(Tsh-Ta)			
104	+ASH*HCVSHA*(TSH-TA) (8018.701017314)	'		
105	'Ash*hrsha*(Tsh-Ta)			
106	+ASH*HRSHA*(TSH-TA) (6908.862835353)	'		
107	+QCHCV+QSHR (14927.56385266)	'		
108	--	------------------------	------------------------	------------------------
109	--	------------------------	------------------------	------------------------

```
FKILN.WK1  ** Range CONST (A55..J109) +VAL **
age 24
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |              -J-                   |
55   |+F61 (0)                            |
56   |*|                                  |
57   |*|                                  |
58   |*|                                  |
59   |*|                                  |
60   |*|                                  |
61   |*|                                  |
62   |*|                                  |
63   |*|                                  |
64   |*|                                  |
65   |*|                                  |
66   |*|                                  |
67   |*|                                  |
68   |*|                                  |
69   |*|                                  |
70   |*|                                  |
71   |*|                                  |
72   |*|                                  |
73   |*|                                  |
74   |*|                                  |
75   |*|                                  |
76   |*|                                  |
77   |*|                                  |
78   |*|                                  |
79   |*|                                  |
80   |*|                                  |
81   |*|                                  |
82   |*|                                  |
83   |*|                                  |
84   |*|                                  |
85   |*|                                  |
86   |*|                                  |
87   |*|                                  |
88   |*|                                  |
89   |*|                                  |
90   |*|                                  |
91   |(PH2O+PCO2)*(RR1-RF) (0.031870615278) |
92   |(PH2O+PCO2)*(RR1-RF)*2 (0.0637412305556)|
93   |(PH2O+PCO2)*(RR1-RF)*3 (0.0956118458334)|
94   |                                    |
95   |*|                                  |
96   |                                    |
97   |*|                                  |
98   |                                    |
99   |*|                                  |
100  |*|                                  |
101  |*|                                  |
102  |*|                                  |
103  |*|                                  |
104  |*|                                  |
105  |*|                                  |
106  |*|                                  |
107  |*|                                  |
108  |------------------------------------|
109  |------------------------------------|
```

FKILNLWK1 ** Range E [A109..E128] *VAL **
age 25
FKILNLWK1 FLAME REGION MODELED AS ONE SECTION

	-A-	-B-	-C-	-D-	-E-
109	------------------	----------------------------------	------------------------------------	@INT(@NOW) (32202)	----------------------------
110	'Qss+Qsw+Qsg+Qsf =		+QSS+QSW+QSG+QSF (-5.456968210637E-12)	'EMs =	+EMS (0.8)
111	'Qws+Qww+Qwg+Qwf =		+QWS+QWW+QWG+QWF (-3.637978807091E-11)	'EMw =	+EMW (0.8)
112	'Qgs+Qgw+Qgg+Qgf =		+QGS+QGW+QGG+QGF (5.456968210637E-12)	'FLF =	+FLF (0.8)
113	'Qfs+Qfw+Qfg+Qff =		+QFS+QFW+QFG+QFF (2.910383045673E-11)	'EMf =	+EMF (1)
114					
115	'Ts =Tw = Tg				
116	------------------				
117	'Qws = Qsw	+QWS (-39623.04440461)	+QSW (-9277.160936659)		+C117-B117 (30345.88346795)
118	'Qgs = Qsg	+QGS (-6104.24178883)	+QSG (-8929.722165155)		+C118-B118 (-2825.480376324)
119	'Qgw = Qwg	+QGW (-23248.45635983)	+QWG (-92802.59797963)		+C119-B119 (-69554.1416198)
120	'Qfs = Qsf	+QFS (-142433.3176775)	+QSF (-22378.49550583)		+C120-B120 (120054.8181717)
121	'Qfw =Qwf	+QFW (-507096.3850739)	+QWF (-340001.4623277)		+C121-B121 (167094.9227462)
122	'Qfg = Qgf	+QFG (-78322.45963568)	+QGF (-23150.3278276)		+C122-B122 (55172.13180804)
123	'Qs	+QS (-162280.1989821)			
124	'Qw	+QW (-39.21852042004)		'alt s	
125	'Qg	+QG (-165073.6587062)		'/FSA:FKILN^R/FSC:FKILN^A	
126	'Qf	+QF (342321.872726)			
127		+B125+B124+B123+QF (14928.79651721)			
128					

```
FKILN.WK1  ** Range FLA [I340..U362] *VAL **
age 26
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
    |                     -I-                         |        -J-          |       -K-              |       -L-                   |       -M-               |       -N-
    |
340 |"PREHEAT OF FEUL AND AIR                         |                     |                        |"% FEUL USED SECT 1 =        ||                        |
    |
341 |"Tf1 =                                           |+E58 (2351.901166339)|"TOTAL                  |"SECT. 1 COMBUSTED           |"PREHEATED               |
    |
342 |                                                 |                     |"LB/HR                  |"LB/HR                       |"LB/HR                   |"BTU/HR
    |
343 |"FEUL LB/HR =                                    |                     |1178                    |+M$340*K343 (178)            |+K343-L343 (0)           |+K366*M343 (0)
    |
344 |"CO2 LB/HR =                                     |                     |                        |                             |                         |
    |
345 |"BURNER O2, LB/HR =                              |                     |1653.37                 |+M$340*K345 (653.37)         |+K345-L345 (0)           |+T298*($J$341-60)*M345
 (0)|
346 |"BURNER N2, LB/HR =                              |                     |12163.23                |+M$340*K346 (2163.23)        |+K346-L346 (0)           |+T299*($J$341-60)*M346
 (0)|
347 |"BURNER H2O, LB/HR=                              |                     |128.17                  |+M$340*K347 (28.17)          |+K347-L347 (0)           |+T300*($J$341-60)*M347
 (0)|
348 |                                                 |                     |------------------------|-----------------------------|-------------------------|---------------------
----|
349 |                                                 |                     |@SUM(K347..K343) (3022.77)|@SUM(L347..L343) (3022.77)|@SUM(M347..M343) (0)|@SUM(N347..N343) (0)
    |
350 |                                                 |                     |                        |                             |                         |
    |
351 |"RECIRCULATION FRAC. =                           |                     |                        |"*Mo = X(Mcp + Mxair)        |                         |
    |
352 |"X =                                             |                     |+F61 (0)                |"*Mo/(Mcp + Mxair) =         |+F61*K349/D349 (0)       |
    |
353 |                                                 |                     |                        |                             |                         |
    |
354 |"Qf1 TOTAL = (1-%COMB)Mo(Tf1-To) + 1/3X(Mcp+Mxair)(Tf1-Tg1) |          |                        |                             |                         |
    |
355 |"Qf1 =                                           |+Q1A+Q1B (0)         |+Q1A (0)                |+Q1B (0)                     |                         |
    |
356.|                                                 |                     |                        |                             |                         |
    |
357 |"Qf2 TOTAL = -(1-%COMB)Mo(Tf1-To) + 1/3X(Mcp+Mxair)(Tf2-Tf1) + 2(1/3X(Mcp+Mxair)(Tf2-Tg2) + Mcp((Tf2-Tf1))|    |                             |                         |
    |
358 |"Qf2 =                                           |-Q1A (0)             |+Q2C (0)                |+Q1B*2 (0)                   |                         |+AC404 (0)
    |
359 |"Qf2 =                                           |-Q1A+2*Q1B+Q2C+N358 (0)|                      |                             |                         |
    |
360 |                                                 |                     |                        |                             |                         |
    |
361 |"Qf TOTAL  BTU/HR = X(Mcp + Mxair)*(Tf-Tg) = 3(1/3X(Mcp - Mxair))|     |                        |                             |                         |
    |
362 |"Qf =                                            |+L355*3 (0)          |                        |                             |                         |
    |
```

FKILN.WK1 ** Range FLA [I340..U362] +VAL **
age 27
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-O-	-P-	-Q-	-R-	-S-	-T-	-U-
340		@INT(@NOW) (32202)	*3. Mxair		*Tg1-Tgo BTU/HR =		-D381 (0)
341	*TOTAL	*TOTAL	*4. 1/3X(Mcp+Mxair)		*Tg1-Tg2 BTU/HR =		-J381 (0)
342	*Mcp+Mxair	*Mxair			*-Qg1 BTU/HR = +		+U341+U340 (0)
343	* LB/HR	*LB/HR					
344	569.19+P344 (569.19)	0	*5. Mxair		*Tg2-Tg1 BTU/HR =		-D404 (563560.3450351)
345	59.4+P345 (448.63)	389.23	*6. X(Mcp+Mxair)		*Tg2-Tg3 BTU/HR =		-J404 (0)
346	2163.23+P346 (3452.25)	1289.02			*-Qg2 BTU/HR = +		+U345+U344 (563560.3450351)
347	230.34+P347 (381.96)	151.62					
348	------------------------	------------------------	*9. Mxair		*Tg2-Tg3 BTU/HR =		+P404 (-413861.0979466)
349	@SUM(O347..O343) (4852.03)	@SUM(P347..P343) (1829.87)	*10. Mcp+X(Mcp+Mxair)		*-(Tg3-Tf2) BTU/HR =		+N404 (413867.316849)
350						*0 =	+U348+U349 (6.2209024047471)
351							
352							
353				*+ ==) Tg +			
354							
355				*Qg BTU/HR=	+O6*3.414 (-563561.470823)		
356							
357							
358							
359							
360							
361							
362							

FKILN.WK1 ** Range FLA1 [V341..AG356] +VAL ** (07-07-88 13:44) P

age 28

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-V-	-W-	-X-	-Y-	-Z-
341		"1. QfIA ENTH.CALC. 1/3*I(Mcp+Mzair)(Tf-Tg)			
342		"+Tf =	+TF*1.8-460 (2351.901166339)	"+Tg =	+TG*1.8-460 (1181.966453613)
343			"Cp	"Tg	
344	"1/3I(Mcp+Mzair)		"BTU/LB*F	"BTU/HR	
345	"LB/HR			"OUT	
346	(1/3)*O344*RC (0)	"CO2	+X358+Y358*(X342-60)+Z358*((X342-60)^2) (0.28156867463)	+V346*X346*(X342-60) (0)	+X358+Y358*(Z342-60)+Z358*((Z342-60)^2) (0.250849262829)
347	(1/3)*O345*RC (0)	"O2	+X359+Y359*(X342-60)+Z359*((X342-60)^2) (0.266702057568)	+V347*X347*(X342-60) (0)	+X359+Y359*(Z342-60)+Z359*((Z342-60)^2) (0.253332387819)
348	(1/3)*O346*RC (0)	"N2	+X360+Y360*(X342-60)+Z360*((X342-60)^2) (0.272955290127)	+V348*X348*(X342-60) (0)	+X360+Y360*(Z342-60)+Z360*((Z342-60)^2) (0.259270587935)
349	(1/3)*O347*RC (0)	"H2O	+X361+Y361*(X342-60)+Z361*((X342-60)^2) (0.532717131896)	+V349*(X349*(X342-60)+1060) (0)	+X361+Y361*(Z342-60)+Z361*((Z342-60)^2) (0.486012254488)
350	-------------------			-------------------------------	
351	@SUM(V349..V345) (0)			@SUM(Y350..Y346) (0)	
352		"DEL H GAS, BTU/HR =		+Y351-AA351 (0)	
353			"WATTS	+Q18/3.414 (0)	"Cp IN =
354		"BTU/F =		+Q18/(X342-AA342) (0)	"Cp OUT =
355		"DEL Tg, K =		-+W225*3.414/(Y354*1.8) (ERR)	
356	-------------------	--	--	-------------------------------	--

FKILN.WK1 ** Range FLA1 (V341..AG356) +VAL **
age 29
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-AA-	-AB-	-AC-	-AD-	-AE-
341	"1/3X=		"2. Of28 ENTH CALC. 1/3X(Mcp+Mxair)(Tf2-Tf1)		
342		"Tf2 =	+E59 (2351.901166339)	"Tf1 =	+E58 (2351.901166319)
343	"Tg			"Cp	"Tg
344	"BTU/HR	"1/3X(Mcp+Mxair)		"BTU/LB*F	"BTU/HR
345	"IN	"LB/HR			"OUT
346	+V346*Z346*($Z$342-60) (0)	+V346 (0)	"CO2	+AD358+AE358*(AC342-60)+AF358*((AC342-60)^2) (0.28156867463)	+AB346*AD346*(AC342-60) (0)
347	+V347*Z347*($Z$342-60) (0)	+V347 (0)	"O2	+AD359+AE359*(AC342-60)+AF359*((AC342-60)^2) (0.266702057568)	+AB347*AD347*(AC342-60) (0)
348	+V348*Z348*($Z$342-60) (0)	+V348 (0)	"N2	+AD360+AE360*(AC342-60)+AF360*((AC342-60)^2) (0.272955290127)	+AB348*AD348*(AC342-60) (0)
349	+V349*(Z349*($Z$342-60)+1060) (0)	+V349 (0)	"H2O	+AD361+AE361*(AC342-60)+AF361*((AC342-60)^2) (0.532717131896)	+AB349*(AD349*(AC342-60)+1060) (0)
350	------------------------------	--------------			------------------------------
351	@SUM(AA350..AA346) (0)	+V351 (0)			@SUM(AE350..AE346) (0)
352			"DEL H GAS, BTU/HR =		+AE351-AG351 (0)
353	+Y351/V351/(X342-60) (ERR)			"WATTS	+02C/3.414 (0)
354	+AA351/V351/(Z342-60) (ERR)		"BTU/F =		+02C/(AC342-AE342) (ERR)
355			"DEL Tg, K =		-+06*3.414/(AE354*1.8) (ERR)
356	------------------------------	--------------	------------------------------	------------------------------	------------------------------

```
FKILN.WK1  ** Range FLA1 [V341..AG356] *VAL **
age 30
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
     |                    -AF-                                         |              -AG-               |
341  |                                                                 |                                 |
342  |'1/3I*                                                           |1/3*AC (0)                       |
343  |                                                                 |"]g                              |
344  |                                                                 |"BTU/HR                          |
345  |                                                                 |"IN                              |
346  |+AD358+AE358*(AE342-60)+AF358*((AE342-60)^2) (0.28156867463)     |+AB346*AF346*(AE342-60) (0)      |
347  |+AD359+AE359*(AE342-60)+AF359*((AE342-60)^2) (0.266702057568)    |+AB347*AF347*(AE342-60) (0)      |
348  |+AD360+AE360*(AE342-60)+AF360*((AE342-60)^2) (0.272955290127)    |+AB348*AF348*(AE342-60) (0)      |
349  |+AD361+AE361*(AE342-60)+AF361*((AE342-60)^2) (0.532717131896)    |+AB349*(AF349*(AE342-60)+1060) (0)|
350  |                                                                 |---------------------------------|
351  |                                                                 |@SUM(AG350..AG346) (0)           |
352  |                                                                 |                                 |
353  |"Cp IN =                                                         |+AE351/P298/(AC342-60) (0)       |
354  |"Cp OUT =                                                        |+AG351/P298/(AE342-60) (0)       |
355  |                                                                 |                                 |
356  |-----------------------------------------------------------------|---------------------------------|
```

FKILN.WK1 ** Range H [L292..N340] +VAL **

age 31

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

Row	-L-	-M-	-N-
292	"BASIS : GAS ENTHALPY		
293	--		
294	"FEED LB/HR	11335	"CO2 LB/HR =
295	"% H2O	0.101	"O2 LB/HR
296	"Cp BTU/LB*F, DRY	0.26	"N2 LB/HR
297			"LBS H2O/HR
298	"F/D FILL RATIO	10	"TOTAL LB/HR
299	"% EXCESS AIR SEC. =	0.6558	"MOLES H2O
300	"AIR DENSITY, LB/FT3	28.84/M301 (0.0810907306761)	"MOLES GAS
301	"MOLAR VOL. FT3/MOL	360*(TA*1.8)/536.4 (355.6510067114)	"MOL % H2O
302	"Tair, F	70	"MOL % CO2
303	"HEAT OF VAPOR. BTU/LB	1060	
304	"hcvas BTU/FT^2*F =	+HCVAS/5.68 (0.0028169014008)	
305		"T ABM,K=	+TA (294.4)
306	"BASIS : SOIL ENTHALPY		
307	--	--	
308	"SOIL DRY BASIS, LB2/HR		(1-M295)*M294 (1200.165)
309	"BTU/HR*F =		+M296*M308 (312.0429)
310	"DEL Ts, K =		+M318 (731.9141398062)
311			
312	"QS BTU/HR =	-+QS*3.414*P312 (554024.599325)	
313	"BTU/HR UP TO 212 =	(212-60)*M309 (47430.5208)	
314	"DEL Hv H2O, BTU/HR =	+M295*M294*M303 (142925.1)	
315	"BTU/HR ABOVE 212 =	@IF((+M312-M313))M314,+M312-M313-M314,0) (363668.978525)	
316	"DEL Ts, F =	@IF((+M312-M313))M314,+M315/M309+(212-60),@IF((+M312-M313))0,212-60,+M312/M309)) (1317.445451651)	
317	"DEL Ts, C =	(+M316)/1.8 (731.9141398062)	
318	"DEL TS, K =	+M317 (731.9141398062)	
319			
320	"HEAT LOSS CALC FOR FLAME HHB		
321	--	--	
322	"-Qs SOLID,BTU/HR =	-QS*3.414 (554024.599325)	"(===INCLUDES HEAT OF VAPOR. OF WATER IN FEED SOLID
323	"-Qw WALL,BTU/HR =	-QW*3.414 (133.0920287141)	
324	"-Qg GAS,BTU/HR =	-QG*3.414 (563561.470823)	
325	"SHELL LOSS BTU/HR =	+C66*3.414 (50966.91130977)	
326	"Qf1 OR Qf2 BTU/HR =	+QF1+QF2 (0)	"(==== ENTHALPY CALC FOR RECIRC GAS
327	--	--	" OR FEUL & AIR PREHEATED
328	"TOTAL MM BTU/HR =	@SUM(M326..M322)/1000000 (1.168686873486)	
329			
330	--	--	--
331			
332	"CROSSECTIONAL AREA OF BED =		
333	"= ((D/2)^2)(THIRAD/2-@COS(THIRAD/2)*@SIN(THIRAD/2))		
334	"% FILL =		
335	"SOLID BED VOLUME, m^3 =		
336	"FT^3 =		
337	"CROSECT. AREA OF FREEBOARD, Axt, M^2 =		
338	"FREEBOARD VOLUME, M^3 =		
339	--	--	--
340	"% FEUL USED SECT 1 =	1	

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-O-	-P-	-Q-	-R-	-S-
292		'SEC.6		'|	'COMBUSTION GAS ENTHALPY CALC.
293	'SUM	'FEED	'COMBST.	'|	'Tf =
294	+P294+Q294 (569.1906)		+AF7 (569.1906)	'|	
295	+P295+Q295 (448.72272048)	(67+68/2)*32*H299 (389.32590048)	+AF9 (59.39682)	'|	
296	+P296+Q296 (3452.249278708)	(67+68/2)*3.78389*28*H299 (1289.020583871)	+AF10 (2163.228694836)	'|	
297	+P297+Q297 (381.9568019918)	+Q39*(P296+P295)*H295*H294 (151.6184648435)	+AF11 (230.3383371483)	'|	'CO2
298	+P298+Q298 (4852.11940118)	+P296+P295+P297+P294 (1829.964949194)	+Q296+Q295+Q297+Q294 (3022.154451985)	'|	'O2
299	+P299+Q299 (21.21982233288)	+P297/18 (8.423248046861)	+Q297/18 (12.79657428602)	'|	'N2
300	+P300+Q300 (171.4731744446)	+P299+P295/32+P296/28 (66.62613186083)	@SUM(Q304..Q301) (104.8470425837)	'|	'H2O
301	+Q299/Q300 (0.123750099113)	'CO2 LBm/HR	+AG7 (12.93615)	'|	
302	(+Q294/44)/Q300 (0.075441246375)	'O2 LBm/HR	+AG9 (1.856150625)	'|	
303		'N2 LBm/HR	+AG10 (77.25816767274)	'|	'DEL H GAS, BTU/HR =
304		'H2O LBm/HR	+AG11 (12.79657428602)	'|	
305				'|	'BTU/F =
306				'|	'DEL Tg, K =
307				'|	
308				'|	
309				'|	
310				'|	
311				'|	
312	'Qsl BTU/HR=	0		'|	
313				'|	--
314				'|	'FEED GAS ENTHALPY CALC USED
315				'|	'Tg =
316				'|	
317				'|	
318				'|	
319				+U319/P294 (ERR)	'CO2
320				+U320/P295 (284.2304422669)	'O2
321				+U321/P296 (290.8929036278)	'N2
322				+U322/P297 (1605.289448497)	'H2O
323				'|	
324				'|	
325				'|	'DEL H GAS, BTU/HR =
326				'|	
327				'|	'BTU/F =
328				'|	'DEL Tg, K =
329				'|	
330	------------------------------	------------------------------	------------------------------	------------------------------	
331					
332		((D/2)^2)*(THIRAD/2-@COS(THIRAD/2)*@SIN(THIRAD/2)) (0.089615040261)			
333					
334		+P332/P337 (0.070074010982)			
335		+L*P332 (0.436694091193)			
336		+P335/0.028317 (15.4216227423)			'AVG. DENSITY OF SOLID BED, LB/FT^3 =
337		+RR1^2*@PI-P332 (1.278862719642)			'SOLID FEED RATE, FT^3/HR =
338		+P337*L (6.231898032816)			'RESIDENCE TIME FOR SOLID BED, HR =
339	------------------------------	------------------------------	------------------------------	------------------------------	--
340		@INT(@NOW) (32202)	'3. Mxair		'Tgl-Tgo BTU/HR =

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-T-	-U-	-V-	-W-
292				
293	+TF*1.8-460 (2351.901166339)		'Tg IN =	+T293-100 (2251.901166339)
294	'Cp	'Tg		'Tg
295	'BTU/LB*F	'BTU/HR		'BTU/HR
296		'OUT		'IN
297	+T309+U309*($T$293-60)+V309*(($T$293-60)^2) (0.28156867463)	+Q294*T297*($T$293-60) (367314.3889226)	+T309+U309*($W$293-60)+V309*(($W$293-60)^2) (0.279733298113)	+Q294*V297*($W$293-60) (348997.9313852)
298	+T310+U310*($T$293-60)+V310*(($T$293-60)^2) (0.266702057568)	+Q295*T298*($T$293-60) (36306.58876423)	+T310+U310*($W$293-60)+V310*(($W$293-60)^2) (0.265644881755)	+Q295*V298*($W$293-60) (34584.82756334)
299	+T311+U311*($T$293-60)+V311*(($T$293-60)^2) (0.272955290127)	+Q296*T299*($T$293-60) (1353286.77131)	+T311+U311*($W$293-60)+V311*(($W$293-60)^2) (0.271849788267)	+Q296*V299*($W$293-60) (1288998.470331)
300	+T312+U312*($T$293-60)+V312*(($T$293-60)^2) (0.532717131896)	+Q297*(T300*($T$293-60)+1060) (525386.778711)	+T312+U312*($W$293-60)+V312*(($W$293-60)^2) (0.528746437943)	+Q297*(V300*($W$293-60)+1060) (511111.5414022)
301		--		--
302		@SUM(U301..U297) (2282294.527708)		@SUM(W301..W297) (2183692.770682)
303		+U302-W302 (98601.75702628)		
304	'WATTS	+U303/3.414 (28881.59256774)	'Cp IN =	+U302/P298/(T293-60) (0.544168040804)
305		+U303/(T293-W293) (986.0175702628)	'Cp OUT =	+W302/P298/(W293-60) (0.544412135074)
306		-+D6*3.414/(U305*1.8) (317.5295405023)		
307	'A	'B	'C	
308				
309	0.202394171692	0.000051475613	-7.387E-9	'CO2
310	0.2384537361	0.0000141588	-8E-10	'O2
311	0.2446041076	0.0000137453	-6E-10	'N2
312	0.4407080267	0.0000406037	-2E-10	'H2O
313	--	--	--	--
314				
315	+TG*1.8-460 (1181.966459613)		'Tg IN =	+TA*1.8-460 (69.92)
316	'Cp	'Tg		'Tg
317	'BTU/LB*F	'BTU/HR		'BTU/HR
318		'OUT		'IN
319	+T331+U331*(T315-60)+V331*((T315-60)^2) (0.250849262829)	+P294*T319*($T$315-60) (0)	+T331+U331*(W315-60)+V331*((W315-60)^2) (0.202904082844)	+P294*V319*($W$315-60) (0)
320	+T332+U332*(T315-60)+V332*((T315-60)^2) (0.253332387819)	+P295*T320*($T$315-60) (110658.2728793)	+T332+U332*(W315-60)+V332*((W315-60)^2) (0.23859411267)	+P295*V320*($W$315-60) (921.4774082269)
321	+T333+U333*(T315-60)+V333*((T315-60)^2) (0.259270587935)	+P296*T321*($T$315-60) (374966.9404783)	+T333+U333*(W315-60)+V333*((W315-60)^2) (0.244740401932)	+P296*V321*($W$315-60) (3129.516124691)
322	+T334+U334*(T315-60)+V334*((T315-60)^2) (0.486012254488)	+P297*(T322*($T$315-60)+1060) (243391.5218107)	+T334+U334*(W315-60)+V334*((W315-60)^2) (0.441110795722)	+P297*(V322*($W$315-60)+1060) (161379.0277075)
323		--		--
324		@SUM(U323..U319) (729016.7351684)		@SUM(W323..W319) (165430.0212404)
325		+U324-W324 (563586.713928)		
326	'WATTS	+U325/3.414 (165081.0527029)	'Cp IN =	+U324/P298/(T315-60) (0.355070713144)
327		+U325/(T315-W315) (506.8014101892)	'Cp OUT =	+W324/P298/(W315-60) (9.112968769611)
328		-+D6*3.414/(U327*1.8) (617.7759171899)		
329	'A	'B	'C	
330				
331	0.202394171692	0.000051475613	-7.387E-9	'CO2
332	0.2384537361	0.0000141588	-8E-10	'O2
333	0.2446041076	0.0000137453	-6E-10	'N2
334	0.4407080267	0.0000406037	-2E-10	'H2O
335				
336				100
337				(+P294/100) (13.35)
338				+P336/W337 (1.155177733506)
339	--	--	--	--
340		-D381 (0)		

```
FKILN.WK1  ** Range RAD (A129..E307) *VAL **
age 34
FKILN.WK1 FLAME REGION MODELLED AS ONE SECTION
    |  -A-  |                          -B-                          |                -C-                      |      -D-      |                  -E-                                      |
129 |       |'Qs = ssEs + wsEw + gsEg + fsEf + hcvws(Tw - Ts) + hcvgs(Tg - Ts) |                          |               |                                                           |
130 |       |                                                       |                                         |               |                                                           |
131 |       |'Qw = swEs + wwEw + gwEg + fwEf + hcvgw(Tg - Tw) - hcdwsh(Tw - Tsh)|                           |               |                                                           |
132 |       |                                                       |                                         |               |                                                           |
133 |       |'Qg = sgEs + wgEw + ggEg  + fgEf - hcvgs(Tg - Ts) + hcvgw(Tg - Tw) |                          |               |                                                           |
134 |       |                                                       |                                         |               |                                                           |
135 |       |'Qf = sfEs + wfEw + gfEg  + ffEf                       |                                         |               |                                                           |
136 |       |'Qs                                                    |                                         |               |                                                           |
137 |       |*******************************************************|*****************************************|***************|***********************************************************|
138 |       |                                                       |                                         |               |                                                           |
139 |'Es    |'ss                                                    |'EMs*As                                  |               |+EMS*AS (0.661542609446)                                   |
140 |       |2                                                      |'-ABs*TRgs2*Fws*Fsw*pw*EMs*As            |               |-ABS*TRGS2*FWS*FSW*PW*EMS*AS (-0.002411082816)             |
141 |       |3                                                      |'-ABs*TRgs3*Fws*Fww*Fsw*pw*pw*EMs*As     |               |-ABS*TRGS3*FWS*FWW*FSW*PW*PW*EMS*AS (-0.000138873052)      |
142 |       |4                                                      |'-Fws*TRgs3*Fww*Fww*Fsw*pw*pw*pw*EMs*As  |               |-FWS*TRGS3*FWW*FWW*FSW*PW*PW*PW*EMS*AS (-0.0000105555572)  |
143 |       |5                                                      |'-Fws*TRgs3*Fws*Fsw*Fsw*ps*pw*pw*EMs*As  |               |-FWS*TRGS3*FWS*FSW*FSW*PS*PW*PW*EMS*AS (-0.000003508588)   |
144 |'Qs (= Qs|                                                     |                                         |               |@SUM(E143..E139) (0.658978589416)                          |
145 |       |                                                       |                                         |               |                                                           |
146 |'Ew    |'ws                                                    |'-ABs*TRgw1*Fws*EMw*Aw                   |               |-ABS*TRGW1*FWS*EMW*AW (-0.15405245594)                     |
147 |       |2                                                      |'-ABs*TRgw2*Fws*Fww*pw*EMw*Aw            |               |-ABS*TRGW2*FWS*FWW*PW*EMW*AW (-0.008825719249)             |
148 |       |3                                                      |'-ABs*TRgw3*Fws*Fww*Fww*pw*pw*EMw*Aw     |               |-ABS*TRGW3*FWS*FWW*FWW*PW*PW*EMW*AW (-0.000509861778)      |
149 |       |4                                                      |'-ABs*TRgw3*Fws*Fws*Fsw*ps*pw*EMw*Aw     |               |-ABS*TRGW3*FWS*FWS*FSW*PS*PW*EMW*AW (-0.000169473987)      |
150 |       |5                                                      |'-Fws*TRgw3*Fww*Fww*Fww*pw*pw*pw*EMw*Aw  |               |-FWS*TRGW3*FWW*FWW*FWW*PW*PW*PW*EMW*AW (-0.000038753976)   |
151 |       |6                                                      |'-2*Fws*TRgw3*Fws*Fww*Fsw*ps*pw*pw*EMw*Aw|               |-2*FWS*TRGW3*FWS*FWW*FSW*PS*PW*PW*EMW*AW (-0.000025763025) |
152 |'Qs (= Qw|                                                     |                                         |               |@SUM(E151..E146) (-0.163622027957)                         |
153 |       |                                                       |                                         |               |                                                           |
154 |'Eg    |'gs                                                    |'-ABs*EMg*As                             |               |-ABS*EMG*AS (-0.153516808523)                              |
155 |       |2                                                      |'-ABs*Fws*pw*TRgs11*EMg*Aw               |               |-ABS*FWS*PW*TRGS11*EMG*AW (-0.00196570864)                 |
156 |'Qs (= Qg|                                                     |                                         |               |@SUM(E155..E154) (-0.155482517164)                         |
157 |       |                                                       |                                         |               |                                                           |
158 |'Ef    |'fs                                                    |'-ABs*TRgf1*Ffs*EMf*Af                   |               |-ABS*TRGF1*FFS*EMF*AF (-0.395046937233)                    |
159 |       |2                                                      |'-ABs*TRgf3*ps*pw*Ffs*Fsw*Fws*EMf*Af     |               |-ABS*TRGF3*PS*PW*FFS*FSW*FWS*EMF*AF (-0.000476037475)      |
160 |       |3                                                      |'-TRgf3*ps*pw*pw*Ffs*Fsw*Fww*Fws*EMf*Af  |               |-TRGF3*PS*PW*PW*FFS*FSW*FWW*FWS*EMF*AF (-0.0000036183032)  |
161 |       |4                                                      |'-ABs*TRgf2*pw*Ffw*Fws*EMf*Af            |               |-ABS*TRGF2*PW*FFW*FWS*EMF*AF (-0.024619934615)             |
162 |       |5                                                      |'-ABs*TRgf3*pw*pw*Ffw*Fww*Fws*EMf*Af     |               |-ABS*TRGF3*PW*PW*FFW*FWW*FWS*EMF*AF (-0.001482227747)      |
163 |       |6                                                      |'-TRgf3*pw*pw*pw*Ffw*Fww*Fww*Fws*EMf*Af  |               |-TRGF3*PW*PW*PW*FFW*FWW*FWW*FWS*EMF*AF (-0.000112662337)   |
164 |       |7                                                      |'-TRgf3*pw*pw*ps*Ffw*Fws*Fws*Fsw*EMf*Af  |               |-TRGF3*PW*PW*PS*FFW*FWS*FWS*FSW*EMF*AF (-0.000037448061)   |
165 |       |                                                       |                                         |               |@SUM(E164..E158) (-0.421811430503)                         |
166 |       |                                                       |                                         |               |                                                           |
167 |       |'hcvws                                                 |'+hcvws*(THIrad*D/2)*(Tw-Ts)             |               |+HCVWS*(THIRAD*D/2)*(TW-TS) (19199.51731661)               |
168 |       |'hcvgs                                                 |'+hcvgs*As*(Tg-Ts)                       |               |+HCVGS*AS*(TG-TS) (-4493.780679249)                        |
169 |       |                                                       |                                         |               |                                                           |
170 |'Qs =) |                                                       |                                         |               |                                                           |
171 |       |                                                       |                                         |               |                                                           |
172 |       |'Qw                                                    |                                         |+FSW (0.341757562292)|                                                     |
173 |       |*******************************************************|*****************************************|***************|***********************************************************|
174 |       |                                                       |                                         |               |                                                           |
175 |       |'sw                                                    |'-ABw*TRgs1*Fsw*EMs*As                   |               |-ABW*TRGS1*FSW*EMS*AS (-0.141792942939)                    |
176 |       |2                                                      |'-ABw*TRgs2*Fww*Fsw*pw*EMs*As            |               |-ABW*TRGS2*FWW*FSW*PW*EMS*AS (-0.008153719857)             |
177 |'Es    |3+EMS*AS (1.98462782834)                               |'-ABw*TRgs3*Fww*Fww*Fsw*pw*pw*EMs*As     |               |-ABW*TRGS3*FWW*FWW*FSW*PW*PW*EMS*AS (-0.000469563628)      |
178 |       |4                                                      |'-ABw*TRgs3*Fws*Fsw*Fsw*ps*pw*EMs*As     |               |-ABW*TRGS3*FWS*FSW*FSW*PS*PW*EMS*AS (-0.000156103352)      |
179 |       |5                                                      |'-Fww*TRgs3*Fww*Fww*Fsw*pw*pw*pw*EMs*As  |               |-FWW*TRGS3*FWW*FWW*FSW*PW*PW*PW*EMS*AS (-0.000035696485)   |
180 |       |6                                                      |'-2*Fww*TRgs3*Fws*Fsw*Fsw*ps*pw*pw*EMs*As|               |-2*FWW*TRGS3*FWS*FSW*FSW*PS*PW*PW*EMS*AS (-0.000023730453) |
181 |'Qw (= Qs|                                                     |                                         |               |@SUM(E180..E175) (-0.150631029369)                         |
182 |       |                                                       |                                         |               |                                                           |
183 |       |'ww                                                    |'+EMw*Aw                                 |               |+EMW*AW (2.514755279088)                                   |
184 |'Ew    |2                                                      |'-ABw*TRgw1*Fww*EMw*Aw                   |               |-ABW*TRGW1*FWW*EMW*AW (-0.520569483251)                    |
185 |'+ + Fww|3                                                     |'-ABw*TRgw2*Fww*Fww*pw*EMw*Aw            |               |-ABW*TRGW2*FWW*FWW*PW*EMW*AW (-0.029846524476)             |
```

FKILN.WK1 ** Range RAD (A129..G307) *VAL **
age 35
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-A-		-B-	-C-	-D-	-E-
186		14		'-ABw*TRgw2*Fws*Fsw*ps*EMw*Aw		-ABW*TRGW2*FWS*FSW*PS*EMW*AW (-0.00072074E595)
187		15		'-ABw*TRgw3*Fww*Fww*Fww*pw*pw*EMw*Aw		-ABW*TRGW3*FWW*FWW*FWW*PW*PW*EMW*AW (-0.00172623342)
188		16		'-2*ABw*TRgw3*Fws*Fww*Fsw*ps*pw*EMw*Aw		-2*ABW*TRGW3*FWS*FWW*FSW*PS*PW*EMW*AW (-0.00011662430)
189		17		'-Fww*TRgw3*Fww*Fww*Fww*pw*pw*pw*EMw*Aw		-FWW*TRGW3*FWW*FWW*FWW*PW*PW*PW*EMW*AW (-0.000131056912)
190		18		'-2*Fww*TRgw3*Fws*Fww*Fsw*ps*pw*pw*EMw*Aw		-2*FWW*TRGW3*FWS*FWW*FSW*PS*PW*PW*FWW*AW (-0.000087124541)
191		19		'-Fsw*TRgw3*Fww*Fww*Fws*ps*pw*pw*EMw*Aw		-FSW*TRGW3*FWW*FWW*FWS*PS*PW*PW*EMW*AW (-0.0000435622711)
192		110		'-Fsw*TRgw3*Fws*Fws*Fsw*ps*ps*pw*EMw*Aw		-FSW*TRGW3*FWS*FWS*FSW*PS*PS*PW*EMW*AW (-0.0000144797511)
193	'Qw (= Qwt					@SUM(E192..E183) (1.95087182463)
194						
195	'Eg	'gw		'-ABw*EAg*Aw		-ABW*EMG*AW (-0.58357118521)
196		12		'-ABw*Fww*pw*TRgw11*EMg*Aw		-ABW*FWW*PW*TRGW11*EMG*AW (-0.00663383432)
197		13		'-ABw*Fsw*ps*TRgw11*EMg*As		-ABW*FSW*PS*TRGW11*EMG*AS (-0.00196164748)
198	'Qw (= Qg)					@SUM(E197..E195) (-0.592166667057)
199						
200	'Ef	'fw		'-ABw*TRgf2*ps*Ffs*Fsw*EMf*Af		-ABW*TRGF2*PS*FFS*FSW*EMF*AF (-0.026739713971)
201		12		'-ABw*TRgf3*ps*pw*Ffs*Fsw*Fww*EMf*Af		-ABW*TRGF3*PS*PW*FFS*FSW*FWW*EMF*AF (-0.001609847735)
202		13		'-TRgf3*ps*pw*pw*Ffs*Fsw*Fww*Fww*EMf*Af		-TRGF3*PS*PW*PW*FFS*FSW*FWW*FWW*EMF*AF (-0.000122362578)
203		14		'-TRgf3*ps*ps*pw*Ffs*Fsw*Fsw*Fws*EMf*Af		-TRGF3*PS*PS*PW*FFS*FSW*FSW*FWS*EMF*AF (-0.000040672344)
204		15		'-ABw*TRgf1*Ffw*EMf*Af		-ABW*TRGF1*FFW*EMF*AF (-1.38266428031B)
205		16		'-ABw*TRgf2*pw*Ffw*Fww*EMf*Af		-ABW*TRGF2*PW*FFW*FWW*EMF*AF (-0.083258877867)
206		17		'-ABw*TRgf3*pw*pw*Ffw*Fww*Fww*EMf*Af		-ABW*TRGF3*PW*PW*FFW*FWW*FWW*EMF*AF (-0.00501254B607)
207		18		'-ABw*TRgf3*pw*ps*Ffw*Fws*Fsw*EMf*Af		-ABW*TRGF3*PW*PS*FFW*FWS*FSW*EMF*AF (-0.001666131162)
208		19		'-TRgf3*pw*pw*ps*Ffw*Fws*Fsw*Fww*EMf*Af		-TRGF3*PW*PW*PS*FFW*FWS*FSW*FWW*EMF*AF (-0.000126640613)
209		110		'-TRgf3*pw*pw*ps*Ffw*Fww*Fws*Fsw*EMf*Af		-TRGF3*PW*PW*PS*FFW*FWW*FWS*FSW*EMF*AF (-0.000126640613)
210		111		'-TRgf3*pw*pw*pw*Ffw*Fww*Fww*Fww*EMf*Af		-TRGF3*PW*PW*PW*FFW*FWW*FWW*FWW*EMF*AF (-0.000380997753)
211						@SUM(E210..E200) (-1.501748713564)
212						
213		'hcvws		'+hcvws*(THIrad*D/2)*(Tw-Ts)		+HCVWS*(THIRAD*D/2)*(TW-TS) (19199.51731661)
214		'hcvgw		'+hcvgw*Aw*(Tg-Tw)		+HCVGW*AW*(TG-TW) (-33029.56344412)
215		'hcdwsh		'+hcdwsh*area3*(Tw-Tsh)		+HCDWSH*AREA3*(TW-TSH) (14927.61128344)
216						
217	'Qw =)					
218						
219		'Qg				
220		**********	**********	**********	**********	**********
221						
222	'Es	'sg		'-(1-TRgs1)*EMs*As		-(1-TRGS1)*EMS*AS (-0.142925819807)
223		12		'-(TRgs1-TRgs2)*Fsw*pw*EMs*As		-(TRGS1-TRGS2)*FSW*PW*EMS*AS (-0.001925304172)
224		13		'-(TRgs2-TRgs3)*Fww*Fsw*pw*pw*EMs*As		-(TRGS2-TRGS3)*FWW*FSW*PW*PW*EMS*AS (-0.000107583041)
225		14		'-(TRgs2-TRgs3)*Fws*Fsw*ps*pw*EMs*As		-(TRGS2-TRGS3)*FWS*FSW*PS*PW*EMS*AS (-0.000031812672)
226	'Qg (= Qs)					@SUM(E225..E222) (-0.144990519694)
227						
228	'Ew	'wg		'-(1-TRgw1)*EMw*Aw		-(1-TRGW1)*EMW*AW (-0.372858741268)
229		12		'-(TRgw1-TRgw2)*Fww*pw*EMw*Aw		-(TRGW1-TRGW2)*FWW*PW*EMW*AW (-0.00753236668)
230		13		'-(TRgw2-TRgw3)*Fww*Fww*pw*pw*EMw*Aw		-(TRGW2-TRGW3)*FWW*FWW*PW*PW*EMW*AW (-0.000372674494)
231		14		'-(TRgw2-TRgw3)*Fws*Fsw*ps*pw*EMw*Aw		-(TRGW2-TRGW3)*FWS*FSW*PS*PW*EMW*AW (-0.000123874028)
232		15		'-(TRgw2-TRgw3)*Fws*Fww*ps*pw*EMw*Aw		-(TRGW2-TRGW3)*FWS*FWW*PS*PW*EMW*AW (-0.000110201121)
233		16		'-(TRgw1-TRgw2)*Fws*ps*EMw*Aw		-(TRGW1-TRGW2)*FWS*PS*EMW*AW (-0.002227346559)
234	'Qg (= Qw)					@SUM(E233..E228) (-0.383225204153)
235						
236	'Eg	'gg		'+EMg*Ag		+EMG*AG (1.409773484258)
237		12		'-ABg11*pw*EMg*Aw		-ABG11*PW*EMG*AW (-0.118614197922)
238		13		'-(pw*Fww*ps*Fws)*pw*TRg11*EMg*Aw		-(PW*FWW*PS*FWS)*PW*TGR11*EMG*AW (-0.002149222902)
239		14		'-(ABg11+pw*TRg11)*Fsw*ps*EMg*As		-(ABG11+PW*TGR11)*FSW*PS*EMG*AS (-0.011154411042)
240	'Qg (= Qg)*2a			'-ABg11*ps*Fsf*As*EMg		-ABG11*PS*SF*AS*EMG (-0.020539236051)
241						@SUM(E240..E236) (1.337316397339)
242						

FKILN.WK1 ** Range RAD [A129..G307] *VAL ** (07-07-88 12:51) P
age 36
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-A-	-B-	-C-	-D-	-E-
243	'Ef	'fg 1.00	'-(1-TRgf1)*EMf*Af		-(1-TRGF1)*EMF*AF (0.227297938209)
244		2	'-(TRgf1-TRgf2)*ps*Ffs*EMf*Af		-(TRGF1-TRGF2)*PS*FFS*EMF*AF (-0.0009595142)
245		3	'-(TRgf2-TRgf3)*ps*pw*Ffs*Fsw*EMf*Af		-(TRGF2-TRGF3)*PS*PW*FFS*FSW*EMF*AF (-0.000066254265)
246		4	'-(TRgf1-TRgf2)*pw*Ffw*EMf*Af		-(TRGF1-TRGF2)*PW*FFW*EMF*AF (-0.003358299702)
247		5	'-(TRgf2-TRgf3)*pw*ps*Ffw*Fws*EMf*Af		-(TRGF2-TRGF3)*PW*PS*FFW*FWS*EMF*AF (-0.000061001986)
248		6	'-(TRgf2-TRgf3)*pw*pw*Ffw*Fww*EMf*Af		-(TRGF2-TRGF3)*PW*PW*FFW*FWW*EMF*AF (-0.000206294495)
249					@SUM(E248..E243) (-0.231949302861)
250					
251		'hcvgs	'+hcvgs*As*(Tg-Ts)		+HCVGS*AS*(TG-TS) (-4493.780679249)
252		'hcvgw	'+hcvgw*Aw*(Tg-Tw)		+HCVGW*AW*(TG-TW) (-33029.56344412)
253					
254	'Qg =)				
255					
256	'Qf				
257	==========	==========	==========	==========	==========
258					
259	'Es	'sf	'-TRgs1*Fsf*EMs*As		-TRGS1*FSF*EMS*AS (-0.341375610965)
260		2	'-TRgs2*pw*Fsw*Fwf*EMs*As		-TRGS2*PW*FSW*FWF*EMS*AS (-0.020316928219)
261	'Qf (= Qs	3	'-TRgs3*pw*pw*Fsw*Fww*Fwf*EMs*As		-TRGS3*PW*PW*FSW*FWW*FWF*EMS*AS (-0.001170210256)
262		4	'-TRgs3*pw*ps*Fsw*Fws*Fsf*EMs*As		-TRGS3*PW*PS*FSW*FWS*FSF*EMS*AS (-0.00037582884)
263		5	'-Fww*TRgs3*Fws*Fsf*Fsw*ps*pw*pw*EMs*As		-FWW*TRGS3*FWS*FSF*FSW*PS*PW*PW*EMS*AS (-0.000022853036)
264		6	'-Fwf*TRgs3*Fww*Fww*Fsw*pw*pw*pw*EMs*As		-FWF*TRGS3*FWW*FWW*FSW*PW*PW*PW*EMS*AS (-0.000071157012)
265		7	'-Fwf*TRgs3*Fws*Fsw*Fsw*ps*pw*pw*EMs*As		-FWF*TRGS3*FWS*FSW*FSW*PS*PW*PW*EMS*AS (-0.000123652023)
266					@SUM(E265..E259) (-0.363356240353)
267					
268	'Ew	'wf	'-TRgw1*Fwf*EMw*Aw		-TRGW1*FWF*EMW*AW (-1.29811911383)
269		2	'-TRgw2*pw*Fww*Fwf*EMw*Aw		-TRGW2*PW*FWW*FWF*EMW*AW (-0.07436969947 3)
270		3	'-TRgw3*pw*pw*Fww*Fww*Fwf*EMw*Aw		-TRGW3*PW*PW*FWW*FWW*FWF*EMW*AW (-0.004296337347)
271	'Qf (= Qw	4	'-TRgw3*pw*ps*Fww*Fws*Fsf*EMw*Aw		-TRGW3*PW*PS*FWW*FWS*FSF*EMW*AW (-0.001379826809)
272		5	'-ps*TRgw2*Fws*Fsf*EMw*Aw		-PS*TRGW2*FWS*FSF*EMW*AW (-0.023884834181)
273		6	'-TRgw3*ps*pw*Fws*Fsw*Fwf*EMw*Aw		-TRGW3*PS*PW*FWS*FSW*FWF*EMW*AW (-0.001428068254)
274		7	'-Fsw*TRgw3*Fwf*Fww*Fws*ps*pw*pw*EMw*Aw		-FSW*TRGW3*FWF*FWW*FWS*PS*PW*PW*EMW*AW (-0.000086836591)
275		8	'-Fwf*TRgw3*Fww*Fww*Fww*pw*pw*pw*EMw*Aw		-FWF*TRGW3*FWW*FWW*FWW*PW*PW*PW*EMW*AW (-0.000261247521)
276		9	'-Fww*TRgw3*Fws*Fww*Fsf*ps*pw*pw*EMw*Aw		-FWW*TRGW3*FWS*FWW*FSF*PS*PW*PW*EMW*AW (-0.000083903172)
277		10	'-Fwf*TRgw3*Fws*Fww*Fsw*ps*pw*pw*EMw*Aw		-FWF*TRGW3*FWS*FWW*FSW*PS*PW*PW*EMW*AW (-0.000086836591)
278		11	'-Fsf*TRgw3*Fws*Fws*Fsw*ps*ps*pw*EMw*Aw		-FSF*TRGW3*FWS*FWS*FSW*PS*PS*PW*EMW*AW (-0.000027888745)
279					@SUM(E278..E268) (-1.404024592352)
280					
281	'Eg	'gf	'-Af*EMg		-AF*EMG (-0.568413092089)
282		2	'-TRgf11*pw*Fwf*Aw*EMg		-TRGF11*PW*FWF*AW*EMG (-0.016530671911)
283	'Qf (= Qg	3	'-TRgf11*ps*Fsf*As*EMg		-TRGF11*PS*FSF*AS*EMG (-0.004723049117)
284					@SUM(E283..E281) (-0.589667213117)
285					
286	'Ef	'ff	'+EMf*Af		+EMF*AF (2.449436960151)
287		2	'-TRgf2*ps*Fsf*Ffs*EMf*Af		-TRGF2*PS*FSF*FFS*EMF*AF (-0.064377577645)
288		3	'-TRgf3*ps*pw*Ffs*Fsw*Fwf*EMf*Af		-TRGF3*PS*PW*FFS*FSW*FWF*EMF*AF (-0.004011317713)
289	'Qf (= Qf	4	'-TRgf2*pw*Ffw*Fwf*EMf*Af		-TRGF2*PW*FFW*FWF*EMF*AF (-0.207459254774)
290		5	'-TRgf3*pw*pw*Ffw*Fww*Fwf*EMf*Af		-TRGF3*PW*PW*FFW*FWW*FWF*EMF*AF (-0.012489954528)
291		6	'-TRgf3*pw*ps*Ffw*Fws*Fsf*EMf*Af		-TRGF3*PW*PS*FFW*FWS*FSF*EMF*AF (-0.004011317713)
292		7	'-TRgf3*pw*pw*pw*Ffw*Fwf*Fww*Fww*EMf*Af		-TRGF3*PW*PW*PW*FFW*FWF*FWW*FWW*EMF*AF (-0.000759477061)
293		8	'-TRgf3*pw*pw*ps*Ffw*Fws*Fsw*Fwf*EMf*Af		-TRGF3*PW*PW*PS*FFW*FWS*FSW*FWF*EMF*AF (-0.000252444115)
294		9	'-TRgf3*ps*pw*pw*Ffs*Fsw*Fww*Fwf*EMf*Af		-TRGF3*PS*PW*PW*FFS*FSW*FWW*FWF*EMF*AF (-0.000243916323)
295		10	'-TRgf3*pw*pw*ps*Ffw*Fww*Fws*Fsf*EMf*Af		-TRGF3*PW*PW*PS*FFW*FWW*FWS*FSF*EMF*AF (-0.000243916323)
296		11	'-TRgf3*ps*ps*pw*Ffs*Fsw*Fsf*Fws*EMf*Af		-TRGF3*PS*PS*PW*FFS*FSW*FSF*FWS*EMF*AF (-0.000078337024)
297					@SUM(E296..E286) (2.155509446920)
298	'Qf =)				==========
299					

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-A-	-B-	-C-	-D-	-E-
300					
301					
302					
303			'Qs =		
304			'Qw =		
305			'Qg =		
306			"Qf =		
307					

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-F-	-G-
129	@INT(@NOW) (32202)	
130		'/rnc{?}~~{End}{Down}{End}{Down}{?}/xg\a~
131		
132		
133	"FLF =	+FLF (0.8)
134	"EMs =	+EMS (0.8)
135	"EMw =	+EMW (0.8)
136	"EMf =	+EMF (1)
137	^Watts	^BTU/HR
138		
139		
140		
141		
142		
143		
144	@SUM(E143..E139)+ES (40585.38260765)	+QSS*3.414 (138558.4962225)
145		
146		
147		
148		
149		
150		
151		
152	@SUM(E151..E146)+EW (-39623.04440461)	+QWS*3.414 (-135273.0735973)
153		
154		
155		
156	@SUM(E155..E154)+EG (-6104.24178883)	+QGS*3.414 (-20839.88146706)
157		
158		
159		
160		
161		
162		
163		
164		
165	+E165+EF (-142433.3176775)	+QFS*3.414 (-486267.3465511)
166		
167	-+E167 (-19199.51731661)	+F167*3.414 (-65547.15211893)
168	-+E168 (4493.780679249)	+F168*3.414 (15341.76723895)
169	==	
170	@SUM(F168..F144) (-162280.1989821)	+QS*3.414 (-554024.599325)
171		
172		
173		
174		
175		
176		
177		
178		
179		
180		
181	@SUM(E180..E175)+ES (-9277.160936659)	+QSW*3.414 (-31672.22743775)
182		
183		
184		
185		

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-F-	-G-
186		
187		
188		
189		
190		
191		
192		
193	(@SUM(E192..E183)*EW (472427.1047119)	+QWW*3.414 (1612866.135486)
194		
195		
196	'*	
197		
198	(@SUM(E197..E195)*EG (-23248.45635983)	+QGW*3.414 (-79370.23001246)
199		
200		
201		
202		
203		
204		
205		
206		
207		
208		
209		
210		
211	+E211*EF (-507096.3850739)	+QFW*3.414 (-1731227.058642)
212		
213	+E213 (19199.51731661)	+F213*3.414 (65547.15211093)
214	-E214 (33029.56344412)	+F214*3.414 (112762.5295982)
215	+E215 (14927.61128344)	+F215*3.414 (50962.06492166)
216	**************************************	
217	(@SUM(F215..F179) (-39.21852042004)	+QW*3.414 (-133.8920287141)
218		
219		
220	@INT(@NOW) (32202)	
221		
222		
223		
224		
225		
226	(+E226)*ES (-8929.722165155)	+QSG*3.414 (-30486.07147184)
227		
228		
229		
230		
231		
232		
233		
234	(@SUM(E233..E228))*EW (-92802.59797963)	+QWG*3.414 (-316828.0695024)
235		
236		
237		
238		
239		
240		
241	(@SUM(E240..E236))*EG (52503.0259763)	+QGG*3.414 (179245.3306831)
242		

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-F-	-G-
243		
244		
245		
246		
247		
248		
249	@SUM(E248..E243)*EF (-78322.45963568)	+DFG*3.414 (-267392.8771962)
250		
251	+E251 (-4493.780679249)	+F251*3.414 (-15341.76723895)
252	+E252 (-33029.56344412)	+F252*3.414 (-112762.9295982)
253	==	
254	@SUM(F252..F224) (-165073.6587062)	+DG*3.414 (-563561.470823)
255		
256		
257	@INT(@NOW) (32202)	
258		
259		
260		
261		
262		
263		
264		
265		
266	@SUM(E265..E259)*ES (-22378.49950583)	+DSF*3.414 (-76400.19731292)
267		
268		
269		
270		
271		
272		
273		
274		
275		
276		
277		
278		
279	@SUM(E278..E268)*EW (-340001.4623277)	+DWF*3.414 (-1160764.992386)
280		
281		
282		
283		
284	@SUM(E283..E281)*EG (-23150.32782764)	+DGF*3.414 (-79035.21920358)
285		
286		
287		
288		
289		
290		
291		
292		
293		
294		
295		
296		
297	+E297*EF (727852.1623872)	+QFF*3.414 (2484887.282389)
298	==	==
299	@SUM(F298..F262) (342321.872726)	+QF*3.414 (1168686.873486)

```
FKILN.WK1  ** Range RAD (A129..G307) *VAL **
age 41
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
    |                  -F-                  |                  -G-                 |
300 |                                       |                                      |
301 |****************************************|                                      |
302 |                                       |                                      |
303 |+DS (-162280.1989821)                  |+F303*3.414 (-554024.599325)          |
304 |+DW (-39.21852042004)                  |+F304*3.414 (-133.8920287141)         |
305 |+DG (-165073.6587062)                  |+F305*3.414 (-563561.470823)          |
306 |+DF (342321.872726)                    |+F306*3.414 (1168686.873486)          |
307 |****************************************|                                      |
```

FKILN.WK1 ** Range T (A309..F344) *VAL ** (07/09/88 13:53) P

age 42

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

```
    |                          -A-                          |                          -B-                          |
309 |                                                       |"CALCULATION OF GAS TRANSMISIVITY FOR ITS OWN RADIATION |
310 |                                                       |                                                       |
311 |                                                       |'sg                                                    |
312 |                                                       |2                                                      |
313 |                                                       |3                                                      |
314 |                                                       |4                                                      |
315 |                                                       |                                                       |
316 |                                                       |                                                       |
317 |                                                       |'wg                                                    |
318 |                                                       |2                                                      |
319 |                                                       |3                                                      |
320 |                                                       |4                                                      |
321 |                                                       |5                                                      |
322 |                                                       |6                                                      |
323 |                                                       |                                                       |
324 |                                                       |                                                       |
325 |                                                       |                                                       |
326 |                                                       |'fg     1.00                                           |
327 |                                                       |2                                                      |
328 |                                                       |3                                                      |
329 |                                                       |4                                                      |
330 |                                                       |5                                                      |
331 |                                                       |6                                                      |
332 |                                                       |                                                       |
333 |                                                       |                                                       |
334 |"TRgl1 = (-(Tfg+Twg+Tsg)-EMg*(Af+ABw*Aw+ABs*As))/(EMg*(pw*Aw*(Fwf+ABw*Fww+ABs*Fws)+ps*As*(Fsf+ABw*Fsw)))|                |
335 |"=                                                     |(-(TFG+TWG+TSG)-EMG*(AF+ABW*AW+ABS*AS))/(EMG*(PW*AW*(FWF+ABW*FWW+ABS*FWS)+PS*AS*(FSF+ABW*FSW))) (0.186977006897)|
336 |                                                       |                                                       |
337 |"TRgsl1 =                                              |'(-tsg-ABs*EMg*As)/(ABs*pw*Fws*EMg*Aw)                 |
338 |"=                                                     |@IF(PW=0,0,(-TSG-ABS*EMG*AS)/(ABS*PW*FWS*EMG*AW)) (0.187333376444)|
339 |                                                       |                                                       |
340 |"TRgwl1 =                                              |'(-twg-ABw*EMg*Aw)/((pw*Fww*Aw+ps*Fsw*As)*ABw*EMg)     |
341 |"=                                                     |(-TWG-ABW*EMG*AW)/((PW*FWW*AW+PS*FSW*AS)*ABW*EMG) (0.186946345394)|
342 |                                                       |                                                       |
343 |"TRgfl1 =                                              |'(-tfg-Af*EMg)/((pw*Fwf*Aw+ps*Fsf*As)*EMg)             |
344 |"=                                                     |@IF(FLF=0,0,(-TFG-AF*EMG)/((PW*FWF*AW+PS*FSF*AS)*EMG)) (0.186956514263)|
```

FKILN.WK1 ** Range F [A309..E344] *VAL **

age 43

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

	-C-	-E-
309		
310		
311	'-(1-TRgg1)*EMs*As	-(1-TRGG1)*EMS*AS (-0.153516408523)
312	'-(TRgg1-TRgg2)*Fsw*pw*EMs*As	-(TRGG1-TRGG2)*FSW*PW*EMS*AS (-0.001831367618)
313	'-(TRgg2-TRgg3)*Fww*Fsw*pw*pw*EMs*As	-(TRGG2-TRGG3)*FWW*FSW*PW*PW*EMS*AS (-0.000103681923)
314	'-(TRgg2-TRgg3)*Fws*Fsw*ps*pw*EMs*As	-(TRGG2-TRGG3)*FWS*FSW*PS*PW*EMS*AS (-0.000030659099)
315		@SUM(E314..E311) (-0.155482517164)
316		
317	'-(1-TRgg1)*EMw*Aw	-(1-TRGG1)*EMW*AW (-0.583571165211)
318	'-(TRgg1-TRgg2)*Fww*pw*EMw*Aw	-(TRGG1-TRGG2)*FWW*PW*EMW*AW (-0.006193258236)
319	'-(TRgg2-TRgg3)*Fww*Fww*pw*pw*EMw*Aw	-(TRGG2-TRGG3)*FWW*FWW*PW*PW*EMW*AW (-0.000350620088)
320	'-(TRgg2-TRgg3)*Fws*Fsw*ps*pw*EMw*Aw	-(TRGG2-TRGG3)*FWS*FSW*PS*PW*EMW*AW (-0.000116545979)
321	'-(TRgg2-TRgg3)*Fws*Fww*ps*pw*EMw*Aw	-(TRGG2-TRGG3)*FWS*FWW*PS*PW*EMW*AW (-0.000103681923)
322	'-(TRgg1-TRgg2)*Fws*ps*EMw*Aw	-(TRGG1-TRGG2)*FWS*PS*EMW*AW (-0.001831367618)
323		@SUM(E322..E317) (-0.592166667057)
324		
325		
326	'-(1-TRgg1)*EMf*Af	-(1-TRGG1)*EMF*AF (-0.568413492089)
327	'-(TRgg1-TRgg2)*ps*Ffs*EMf*Af	-(TRGG1-TRGG2)*PS*FFS*EMF*AF (-0.004409135085)
328	'-(TRgg2-TRgg3)*ps*pw*Ffs*Fsw*EMf*Af	-(TRGG2-TRGG3)*PS*PW*FFS*FSW*EMF*AF (-0.000280591924)
329	'-(TRgg1-TRgg2)*pw*Ffw*EMf*Af	-(TRGG1-TRGG2)*PW*FFW*EMF*AF (-0.015431972797)
330	'-(TRgg2-TRgg3)*pw*ps*Ffw*Fws*EMf*Af	-(TRGG2-TRGG3)*PW*PS*FFW*FWS*EMF*AF (-0.00025834812)
331	'-(TRgg2-TRgg3)*pw*pw*Ffw*Fww*EMf*Af	-(TRGG2-TRGG3)*PW*PW*FFW*FWW*EMF*AF (-0.00087367311
332		@SUM(E331..E326) (-0.589667213117)
333		
334		
335		
336		
337		
338		
339		
340		
341		
342		
343		
344		

```
FKILN.WK1  ** Range 1 [A34..Q53] +VAL **
age 44
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  f Formula      . Integer      + Real        @ macro       b blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat

     ABCDEFGHIJKLMNOPQ
  34 |b " "            |
  35 | """ ""  "   "Fb |
  36 |"""""""" "   ".  |
  37 |"+......  "   "F' |
  38 |"+......  "   "F  |
  39 |".......  "   "+  |
  40 |".......  "   ".  |
  41 |"....... "bb ".  |
  42 |".......      b  |
  43 |"+...... "bb ".  |
  44 |"....... "bb ".  |
  45 |"....... "bb ".  |
  46 |"....... "bb ".  |
  47 |".......  "   "+  |
  48 | """"""" "   ".""|
  49 |"FFFFFFF         |
  50 |""..F.F.  "   "F' |
  51 |"FF.FFF.  "   "F+ |
  52 |"....... "F" F""F|
  53 |"+++++++         |
```

FKILNLWK1 FLAME REGION MODELED AS ONE SECTION

```
LEGEND:  F Formula      . Integer      + Real         m macro       b blank
         ' Text Left    ^ Text Center  " Text Right   \ Repeat

     ABCDEFGHIJKLMNOPQRST
   1 |'                  |
   2 |\\\\\\\\\\\\\\\\\\\|
   3 | •• •• •• •• •• •• •|
   4 | •• •• •• •• •• •• •|
   5 | ••••••••••••••••••|
   6 |\•\••\••\••\••\••\••|
   7 |••FF•FF•FF•FF•FF•FF•|
   8 |••FF•FF•FF•FF•FF•.F•|
   9 |••FF•FF•FF•FF•FF•.F•|
  10 |••FF•FF•FF•FF•FF•.F•|
  11 |••FF•FF•FF•FF•FF•.F•|
  12 |••FF•FF•FF•FF•FF•.F•|
  13 |••FF•FF•FF•FF•FF•.F•|
  14 |••FF•FF•FF•FF•FF•.F•|
  15 |••FF•FF•FF•FF•FF•.F•|
  16 |••F••F••F••F••F••F••|
  17 |••F••F••F••F••F••F••|
  18 | ••••••••••••••••••|
  19 |••FF•FF•FF•FF•FF•FF•|
  20 |\\\\\\\\\\\\\\\\\\\|
  21 |••  •  •  •  •F •  •|
  22 |••  •  •  •  •F •  •|
  23 |••F •F •F •F •F •F •|
  24 |••Fb•Fb•Fb•Fb•Fb•Fb•|
  25 |••Fb•Fb•Fb•Fb•.b•.b•|
  26 | ••b••b••b••b••b••b•|
  27 |••Fb•Fb•Fb•Fb•Fb•Fb•|
  28 |\\\\\\\\\\\\\\\\\\\|
```

```
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real        m macro       b blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat
           A
    UVWXYZABCDEFGHIJ
  2 |\\\\\\\\\\\\\\\\|
  3 | "" "" "" "" "" |
  4 | "" "" "" "" "" |
  5 | """"""""""""""|
  6 |\"\""\""\""\""\"|
  7 |""FF"F."F."FF"FF|
  8 |""FF"F."F."F."FF|
  9 |""FF"FF"FF"FF"FF|
 10 |""FF"FF"FF"FF"FF|
 11 |""FF"FF"FF"FF"FF|
 12 |""FF"F."F."FF"FF|
 13 |""FF"F."F."FF"FF|
 14 |""FF"F."F."FF"FF|
 15 |""FF"F."F."FF"FF|
 16 |"""""""""""F""F"|
 17 |"""""""""""F""F"|
 18 | """"""""""""""|
 19 |""FF"FF"FF"FF"FF|
 20 |\\\\\\\\\\\\\\\\|
 21 |""F "F "F "F "F |
 22 |""F "F "F "F "F |
 23 |""F "F "F "F "F |
 24 |""Fb"Fb"Fb"Fb"Fb|
 25 |"".b".b".b".b".b|
 26 |b""b""b""b""b""b|
 27 |""Fb"Fb"Fb"Fb"Fb|
 28 |\\\\\\\\\\\\\\\\|
```

```
FKILN.WK1  ** Range @ IU33..AJ54] *VAL **
age 47
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real         m macro        b blank
         ' Text Left    ^ Text Center  " Text Right   \ Repeat
           A
    UVWXYZABCDEFGHIJ
 33 I" "              I
 34 I\\\\\\\\ "  "  " I
 35 Ib^^^^^^ "F1^^ ^^I
 36 I """""" \\ \"b\"I
 37 I """""" "  F"bF"I
 38 I\"""""" "  F"bF"I
 39 I".FFFFFF"  F"bF"I
 40 I"FFFFFFF"  F"bF"I
 41 I".FFFFFF"  F"bF"I
 42 I".FFFFFF"  F"bF"I
 43 I".FFFFFF"bbF"bF"I
 44 I".FFFFFF"  F"bF"I
 45 I".FFIFFF"  .Fb.FI
 46 I".FFFFFF"  .Fb.FI
 47 I".FFFFFF"  .Fb.FI
 48 I""FFFFFF"  ""b"FI
 49 I""FFFFFF"bb"" "FI
 50 I """"""     \"b\"I
 51 I"FFFFFF "  FF FFI
 52 I bbbbbb " "F"F"FI
 53 I bbFbbb ""F "bF I
 54 I\\\\\\\\\\\\\\\\\
```

```
FKILN.WK1  ** Range CONST (A55..J1(9) +VAL **
age 48
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula     . Integer     + Real        m macro       b blank
         ' Text Left   ^ Text Center  " Text Right  \ Repeat

     ABCDEFGHIJ
 55 I" F " FF"FI
 56 I"F" F "F "I
 57 I\\\ """\ "I
 58 I ^""FFFb+"I
 59 I"FFFFFF"F"I
 60 I"FFFFFF'F"I
 61 I"FFF".''F"I
 62 I"FFF'F''F"I
 63 I"FF 'FF'F"I
 64 I'bF''FF"F"I
 65 I.F '"F''F"I
 66 I'bFF"F''F"I
 67 I'\F'"F'  "I
 68 I'\F'"F''F"I
 69 I'\FF'F''F"I
 70 I"\F''F''F"I
 71 I'bF''.''F"I
 72 I"FF''F''+"I
 73 I"FF''F'  "I
 74 I"FF'"F''+"I
 75 I'bF''+''+"I
 76 I'bF''+'"F"I
 77 I'bF''+'  "I
 78 I'bF'".''."I
 79 I'bF''F''F"I
 80 I'bF''F''b"I
 81 I   ''F''F"I
 82 I'bF'"F'  "I
 83 I'FF''F''."I
 84 I' F''F''."I
 85 I  b''F''+"I
 86 I" F''F''+"I
 87 I" F''F''."I
 88 I" F'  ''F"I
 89 I  b'" ''F"I
 90 I" F'"F'  "I
 91 I" F''F'  FI
 92 I" F''F'  FI
 93 I" F'  'b FI
 94 I" F'''bb  I
 95 I" F''F'b "I
 96 I\\\'''bb  I
 97 I'b.''F'b "I
 98 I"F+'''bb  I
 99 I'b.'bF'b "I
100 I'b.''bbb "I
101 I'b.'''bb "I
102 I'b.'bF'b "I
103 I'bF'''bb "I
104 I   'bF'b "I
105 I' F'''bb "I
106 I' F'bF'  "I
107 I' F''F'  "I
108 I\\\\\\\\\\\I
```

```
FKIUL.WK1  ** Range CONST [A55..J109] +VAL **
age 49
FKIUL.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real       # macro      o blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat

      ABCDEFGHIJ
 109 |\\\F\\\\\\|
```

```
FKILN.WK1  ** Range E (A109..E128) *VAL **
age 50
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula     . Integer     + Real        @ macro       b blank
         ' Text Left   ^ Text Center " Text Right  \ Repeat

     ABCDE
 109 |\\\F\|
 110 |" F"F|
 111 |" F"F|
 112 |" F"F|
 113 |" F"F|
 114 |    |
 115 |^   |
 116 |\   |
 117 |"FF F|
 118 |"FF F|
 119 |"FF F|
 120 |"FF F|
 121 |"FF F|
 122 |"FF F|
 123 |'F  |
 124 |'F " |
 125 |'F @ |
 126 |'F  |
 127 | F  |
 128 |    |
```

```
FKILN.WK1  ** Range FLA [I340..U362] +VAL **
age 51
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real         m macro        b blank
         ' Text Left    ^ Text Center  " Text Right   \ Repeat

      IJKLMNOPQRSTU
 340 |"  ".  F" " F|
 341 |"F*** **' " F|
 342 |  ******  " F|
 343 |" .FFF""     |
 344 |"     F." " F|
 345 |" +FFFF+" " F|
 346 |" +FFFF+  ' F|
 347 |" +FFFF+    b|
 348 |  \\\\\\" " F|
 349 |  FFFFFF" " F|
 350 |           "F|
 351 |"  '        b|
 352 |" F'F        |
 353 |        '    |
 354 |"            |
 355 |"FFF    "F   |
 356 |bbbb         |
 357 |"bbb         |
 358 |"FFF F       |
 359 |"Fbb         |
 360 | b           |
 361 |"            |
 362 |"F           |
```

```
FKILNLWKI  ** Range FLA1 [V341..AG356] *VAL **                    [illegible]-88 13:57 P
age 52
FKILNLWKI FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real         m macro       b blank
         ' Text Left    ^ Text Center  " Text Right   \ Repeat
           A
     VWXYZABCDEFG
 341 | "   ' "    |
 342 | "F"F "F"F"F|
 343 |  "" "  "" "|
 344 |' "" "' "" "|
 345 |"  " ""  " "|
 346 |F"FFFFF"FFFF|
 347 |F"FFFFF"FFFF|
 348 |F"FFFFF"FFFF|
 349 |F"FFFFF"FFFF|
 350 |\  \ \\  \ \|
 351 |F  F FF  F F|
 352 | " F    " F |
 353 |  "F"F  "F"F|
 354 |b" F"F " F"F|
 355 |b" F    " F |
 356 |\\\\\\\\\\\\|
```

```
FKILNLWK1  ** Range H (L292..W340) +VAL **                                        (10/-0) 88 [illegible]
age 53
FKILNLWK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      * Real         m macro        b blank
         ' Text Left    ^ Text Center  " Text Right   \ Repeat

     LMNOPQRSTUVW
 292 |"   " ""    |
 293 |\  """""F "F|
 294 |".."FbF" "" "|
 295 |"+"FFF" "" "|
 296 |"+"FFF"  " "|
 297 | b"FFF""FFFF|
 298 |".."FFF""FFFF|
 299 |"+"FFF""FFFF|
 300 |"F"FFF""FFFF|
 301 |"F"F"F"  \ \|
 302 |"."F"F"  F F|
 303 |".  "F"" F  |
 304 |"F  "F" "F"F|
 305 | "F    "" F"F|
 306 |"      "" F |
 307 |\\     " """ |
 308 |" F    "     |
 309 |" F    " +++"|
 310 |" F    " +++"|
 311 |       " +++"|
 312 |"F ". " +++"|
 313 |"F  b "\\\\\\|
 314 |"F  b ""     |
 315 |"F     ""F "F|
 316 |"Fb b " "" "|
 317 |"F     " "" "|
 318 |"F     "  " "|
 319 |       F"FFFF|
 320 |"      F"FFFF|
 321 |\\    bF"FFFF|
 322 |"F"   bF"FFFF|
 323 |"Fb   b"  \ \|
 324 |"Fb   b"  F F|
 325 |"F    b"" F  |
 326 |"F"   b" "F"F|
 327 |\\"   b"" F"F|
 328 |"F    b"" F  |
 329 |       b" """ |
 330 |\\\\\\\\     |
 331 |          +++"|
 332 |"    F    +++"|
 333 |"    b    +++"|
 334 |"    F    +++"|
 335 |"    F        |
 336 |"    F  "    .|
 337 |"    F  "    F|
 338 |"    F  "    F|
 339 |\\\\\\\\\\\\\\|
 340 |".   F" " F   |
```

```
FKILN.WK1  ** Range MAP (A129..G307) *VAL **
age 54
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer     + Real        m macro       b blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat

     ABCDEFG
 129 |'    F |
 130 |      m|
 131 |'      |
 132 |       |
 133 |'    "F|
 134 |     "F|
 135 |'    "F|
 136 |'    "F|
 137 | \\\\^^|
 138 |       |
 139 |''' F  |
 140 | .' F  |
 141 | .' F  |
 142 | .' F  |
 143 | .' F  |
 144 |'   FFF|
 145 | b     |
 146 |''' F  |
 147 |b.'bF  |
 148 | .' F  |
 149 | .' F  |
 150 | .' F  |
 151 | .' F  |
 152 |'   FFF|
 153 |       |
 154 |''' F  |
 155 | .' F  |
 156 |'   FFF|
 157 |       |
 158 |''' F  |
 159 | .' F  |
 160 | .' F  |
 161 | .' F  |
 162 | .' F  |
 163 | .' F  |
 164 | .' F  |
 165 |    FFF|
 166 |       |
 167 | '' FFF|
 168 | '' FFF|
 169 |      \|
 170 |'    FF|
 171 |       |
 172 | ' F   |
 173 | \\\\  |
 174 |       |
 175 | '' F  |
 176 | .' F  |
 177 |'F' F  |
 178 | .' F  |
 179 | .' F  |
 180 | .' F  |
 181 |'   FFF|
 182 |    b  |
```

```
FKILN.WK1  ** Range RAD [A129..G307] +VAL **                                   [07-09-88 13:58] P
age 55
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula     . Integer     + Real        m macro       b blank
         ' Text Left   ^ Text Center " Text-Right  \ Repeat

     ABCDEFG
183 | '' F  |
184 |'.' F  |
185 |'.' F  |
186 | .' F  |
187 | .' F  |
188 | .' F  |
189 | .' F  |
190 | .' F  |
191 | .' F  |
192 | .' F  |
193 |'   FFF|
194 |    b  |
195 |''' F  |
196 | .' F" |
197 | .' F  |
198 |'   FFF|
199 |       |
200 |''' F  |
201 | .' F  |
202 | .' F  |
203 | .' F  |
204 | .' F  |
205 | .' F  |
206 | .' F  |
207 | .' F  |
208 | .' F  |
209 | .' F  |
210 | .' F  |
211 |    FFF|
212 |       |
213 | '' FFF|
214 | '' FFF|
215 | '' FFF|
216 |      \|
217 |'    FF|
218 |       |
219 |'      |
220 | \\\\F |
221 |       |
222 |''' F  |
223 | .' F  |
224 | .' F  |
225 | .' F  |
226 |'   FFF|
227 |       |
228 |''' F  |
229 | .' F  |
230 | .' F  |
231 | .' F  |
232 | .' F  |
233 | .' F  |
234 |'   FFF|
235 |       |
236 |''' F  |
```

FKILN.WKI ** Range RAD [A129..G307] +VAL ** (07-09-88 11:58) P
age 56
FKILN.WKI FLAME REGION MODELED AS ONE SECTION
LEGEND: F Formula . Integer * Real ● macro b blank
' Text Left ^ Text Center " Text Right \ Repeat

```
    ABCDEFG
237 | .' F  |
238 | .' F  |
239 | .' F  |
240 |'"' F  |
241 |    FFF|
242 |    b  |
243 |"'' F  |
244 | .' F  |
245 | .' F  |
246 | .' F  |
247 | .' F  |
248 | ." F  |
249 |    FFF|
250 |       |
251 | '' FFF|
252 | '' FFF|
253 |      \|
254 |'    FF|
255 |       |
256 |"      |
257 |\\\\\\F|
258 |       |
259 |"'' F  |
260 | .' F  |
261 |".' F  |
262 | .' F  |
263 | .' F  |
264 | .' F  |
265 | .' F  |
266 |    FFF|
267 |       |
268 |"'' F  |
269 | .' F  |
270 | .' F  |
271 |".' F  |
272 | .' F  |
273 | .' F  |
274 | .' F  |
275 | .' F  |
276 | .' F  |
277 | .' F  |
278 | .' F  |
279 |    FFF|
280 |       |
281 |"'' F  |
282 | .' F  |
283 |".' F  |
284 |    FFF|
285 |       |
286 |"'' F  |
287 | .' F  |
288 | .' F  |
289 |".' F  |
290 | .' F  |
```

```
FKILN.WK1  ** Range RAD (A129..G307) +VAL **
age 57
FKILN.WK1 FLAME REGION MODELED AS ONE SECTION
LEGEND:  F Formula      . Integer      + Real        @ macro       b blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat

      ABCDEFG
 291 | .' F  |
 292 | .' F  |
 293 | .' F  |
 294 | .' F  |
 295 | .' F  |
 296 | .' F  |
 297 |    FFF|
 298 |"   \\\|
 299 |     FF|
 300 |       |
 301 |\\\\\\\|
 302 |       |
 303 |  "  FF|
 304 |  "  FF|
 305 |  "  FF|
 306 |  "  FF|
 307 |\\\\\\\|
```

FKILN.WK1 FLAME REGION MODELED AS ONE SECTION

```
LEGEND:  F Formula      . Integer      + Real        @ macro        b blank
         ' Text Left    ^ Text Center  " Text Right  \ Repeat

      ABCDEF
 309 | "     |
 310 |       |
 311 | '' F  |
 312 | .' F  |
 313 | .' F  |
 314 | .' F  |
 315 |    F  |
 316 |    b  |
 317 | '' F  |
 318 | .' F  |
 319 | .' F  |
 320 | .' F  |
 321 | .' F  |
 322 | .' F  |
 323 |    F  |
 324 |    b  |
 325 |    b  |
 326 | '' F  |
 327 | .' F  |
 328 | .' F  |
 329 | .' F  |
 330 | .' F  |
 331 | ." F  |
 332 |    F  |
 333 |       |
 334 |"      |
 335 |"F     |
 336 |       |
 337 |"'     |
 338 |"F     |
 339 | b     |
 340 |"'     |
 341 |"F     |
 342 | b     |
 343 |"'     |
 344 |"F     |
```

Appendix F

Program Listing for Indirect Direct Fired Kiln

	A	B	C	D	E	F	G	H	I
1	FILE:	HMB WKS				by: D M PITTS			
2			INPUT TEMPLATE 1		PRIMARY CHAMBER WASTE DATA				
3		PRIMARY	-------- BURNER WASTES----|			|--------CHAMBER WASTES---|			
4	NAME:	AUX FUEL	WASTE 1	WASTE 2	WASTE3	WASTE 4	WASTE 5	WASTE 6	
5	% C	87 21	0.00	0.00	0.00	0 00	0 00	0 00	
6	% H2	12 62	0 00	0 00	0.00	0 00	0 00	0 00	
7	% O2	0 00	0 00	0.00	0.00	0 00	0 00	0 00	
8	% N2	0.00	0 00	0.00	0.00	0 00	0 00	0 00	
9	% WATER	0 00	0 00	0 00	0 00	0 00	0 00	0 00	
10	% CL	0 00	0.00	0.00	0.00	0.00	0 00	0 00	
11	% S	0 17	0 00	0 00	0.00	0 00	0 00	0 00	
12	% BR	0 00	0 00	0 00	0.00	0 00	0 00	0 00	
13	% F	0 00	0.00	0.00	0.00	0 00	0 00	0 00	
14	% SALT	0 00	0 00	0 00	0.00	0 00	0 00	0 00	
15	% ASH	0.00	0 00	0 00	0.00	0 00	0 00	0 00	
16		--------	--------	--------	--------|	--------	--------	-------|	
17	TOTAL	100 00	0 00	0 00	0 00	0 00	0 00	0 00	
18	LB/HR	----	0 00	0 00	0 00	0.00	0 00	0.00	
19	BTU/LB	19188	0	0	0	0	0	0	
20	TEMP F	60	60	60	60	60	60	60	
21	BTU/LB F	0 50	0 50	0 50	0.50	0 50	0 50	0 50	

22 TEMPLATE 2 PRIMARY BURNER AND CHAMBER COMBUSTION CONDITIONS/CALCULATION

23			
24	% EXCESS AIR FOR FUELS TO BURNER	========>	10 00
25	% EXCESS AIR FOR WASTES TO CHAMBER	========>	10.00
26	RADIATION LOSS (MM BTU/HR)	========>	1 16 <=+Qgo
27	AIR TEMP F	========>	60.00
28	AIR HUMIDITY (LB/LB DRY AIR)	========>	0 01
29	% ASH IN EXIT	========>	0 00
30	% SALT IN EXIT	========>	0 00
31			
32	PYROLYSIS (1 = YES 0 = NO)	========>	0
33	HEAT OF PYROLYSIS BTU/LB	========>	360.00
34	AVG MOL WEIGHT OF PYROLYSIS PRODUCTS	========>	50 00
35	% FIXED CARBON IN ASH	========>	0.00
36	SPECIFIC HEAT OF ASH (BTU/LB F)	========>	0 27
37	DESIRED ASH DISCHARGE TEMPERATURE F	========>	60.00 <- USED IF INPUT
38			
39	DESIRED OR "GUESS" TEMPERATURE F	========>	2200.60 <=+Tgo
40	LBS/HR AUX FUEL	========>	70 00

41 HEAT IN = 1.355 HEAT OUT = 2.003 DELTA H = -0.64845

42
43
44
45
46
47
48
49
50
51
52
53 ....

54 PAUX LB/HR = 70 00

55 HEAT IN = 1 355 HEAT OUT = 2 003 DELTA H = -0 6485

PRIMARY BURNER AND CHAMBER MASS AND HEAT BALANCE RESULTS

J / K	(1) TOTAL WASTE + FUEL LB/HR	(1) LB-M/HR	(2) AUX FUEL TO BURNER LB/HR	(2) LB-M/HR	(3) WASTE TO BURNER LB/HR	(3) LB-M/HR
C	61 05	5.09	61 05	5.09	0 00	0.00
H2	8 83	4 42	8.83	4 42	0.00	0 00
O2	0 00	0.00	0 00	0.00	0 00	0.00
N2	0 00	0 00	0 00	0 00	0.00	0.00
WATER	0 00	0 00	0 00	0 00	0.00	0.00
CL	0 00	0 00	0 00	0 00	0 00	0.00
S	0 12	0 00	0.12	0 00	0 00	0.00
BR	0 00	0.00	0 00	0 00	0.00	0.00
F	0 00	0 00	0.00	0 00	0.00	0.00
SALT	0 00	----	0.00	----	0.00	----
ASH	0 00	----	0 00	----	0.00	----
	--------	--------	--------	--------	--------	--------
TOTAL	70 00	9 51	70 00	9 51	0.00	0.00
SCFM						
ACFM						
TEMP F	ERR		60		ERR	
ENTHALPY	0 000		0.000		0.000	
HEAT REL	1 343		1.343		0.000	
	--------		--------		--------	
MM BTU/HR	1 343		1.343		0.000	

PRIMARY CHAMBER HEAT BALANCE	WASTE	AUX FUEL	IN AIR
MM BTU/HR	0 000	1 343	0.012

PRIMARY COMBUSTION CHAMBER SUMM

TEMP = 2201 F	LBS/HR IN	LBS/HR OUT	MM BTU/HR IN	MM BTU/HR OUT	A	B
AUX FUEL	70.00	----	1 343	----		
WASTE TO BURNER	0 00	----	0.000	----		
WASTE TO CHAMBER	0.00	----	0.000	----		
STOIC AIR TO BURNER	1006.95	----	0.000	----		
XS AIR TO BURNER	100.70	----	0 000	----	0.20	0.00
STOIC AIR TO CHAMBER	0.00	----	0 000	----	0.44	0.00
XS AIR TO CHAMBER	0.00	----	0.000	----	0.24	0.00
AIR HUMIDITY	11 08	----	0 012	----	0.24	0.00
PYRO PRODUCTS	0.00	0.00	0.000	0 000	0.44	0.00
COMBUSTION GAS	0.00	1188 73	0 000	0.839	0.19	0.00
SOLIDS OUT BOTTOM	0.00	0.00	0 000	0.000	0.15	0.00
HEAT OF PYROLYSIS	----	----	----	0.000	0.08	0.00
HEAT LOSS	----	----	----	1 164	0.35	0.00
	---------	--------	-----------	--------		
TOTAL	1188.73	1188 73	1 355	2.003		

AIR SCFM: BURNER = 246 89 CHAMBER = 0.00 OVERALL = 246.89

% XS AIR OOVERALL = 10 00% OFF-GAS ACFM = 1335

V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM AN A AP AQ

	(4) WASTE TO CHAMBER LB/HR	LB-M/HR	(5) PYROLSIS PRODUCTS LB/HR	LB-M/HR	(6) SOLIDS OUT BOTTOM LB/HR	LB-M/HR		(7) TOTAL AIR LB/HR	LB-M/HR	(8) AIR TO BURNER LB/HR	LB-M/HR	(9) AIR TO CHAMBER LB/HR	LB-M/HR	(10) COMBUSTION PRODUCTS LB/HR	LB-M/HR
	0.00	0.00	0.00	0.00	0.00	0.00	CO2	0.00	0.00	0.00	0.00	0.00	0.00	223.84	5.09
	0.00	0.00	0.00	0.00	0.00	0.00	PYRO GAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	O2	256.94	8.03	256.94	8.03	0.00	0.00	23.36	0.73
	0.00	0.00	0.00	0.00	0.00	0.00	N2	850.71	30.38	850.71	30.38	0.00	0.00	850.71	30.38
	0.00	0.00	0.00	0.00	0.00	0.00	WATER	11.08	0.62	11.08	0.62	0.00	0.00	90.58	5.03
	0.00	0.00	0.00	0.00	0.00	0.00	HCL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	SO2	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	HBR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	HF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	----	0.00	----	0.00	----	SALT	----	----	----	----	----	----	0.00	----
	0.00	----	0.00	----	0.00	----	ASH	----	----	----	----	----	----	0.00	----
	0.00	0.00	0.00	0.00	0.00	0.00	TOTAL	1118.73	39.03	1118.73	39.03	0.00	0.00	1188.73	41.24

	(4)	(5)	(6)		(7)	(8)	(9)	(10)
		0		SCFM	247	247	0	261
		0		ACFM	247	247	0	1335
	ERR	2201	60	TEMP F	60	60	60	2201
	0.000	0.000	0.000	ENTHALPY	0.012	0.012	0.000	0.839
	0.000	0.000	0.000	HEAT REL	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	MM BTU/HR	0.012	0.012	0.000	0.839

OUT — HEAT IN -

TOTAL	OFF-GAS	ASH	HEAT OF PYROLYSIS	HEAT LOSS	TOTAL	HEAT IN -
1.355	0.839	0.000	0.000	1.164	2.003	-0.648

TEMPLATE 8 COMPONENT HEAT BALANCE BTU/HR

C			(5) PYROLYS PRODUCTS	(7) TOTAL AIR	(8) AIR TO BURNER	(9) AIR TO CHAMBER	(10) COMBUST PRODUCTS	(11) TOTAL OFF GAS
-0.00	CO2	CO2	0	0	0	0	133555	133555
-0.00		PYRO GAS	0	0	0	0	0	0
-0.00	O2	O2	0	0	0	0	13255	13255
-0.00	N2	N2	0	0	0	0	494004	494004
-0.00	H2O	WATER	0	11741	11741	0	198146	198146
-0.00		HCL	0	0	0	0	0	0
-0.00		SO2	0	0	0	0	109	109
-0.00		HBR	0	0	0	0	0	0
0.00		HF	0	0	0	0	0	0
		SALT	INCL	0	0	0	0	0
		ASH	INCL	0	0	0	0	0
		TOTAL	0	11741	11741	0	839069	839069

```
alt e     @sum((Up)
alt d     /c~.(End)(
alt c     /c~(Right)
~-(TRG(r)-TRG(r))
print macro \W
alt w  /pprrad~agppq
alt r  /pprconst~agRCONST2~
alt v
/pprrad2~agppq
ALT P
/pprrad~aupq
/pprrad2~agppq
/pprconst~agRCONST2~
```

```
          AQ        AR        AS        AT        AU        AV        AW        AX        AY        AZ
-- ----------------------------------------------------------------------------------------------------
 1
 2 ----------------------------------------
 3 |                  |       (11)              |
 4  PRODUCTS          |    TOTAL OFF-GAS        |
 5   LB-M/HR          |     LB/HR    LB-M/HR    |
 6  --------          | ---------- --------     |
 7      5.09          |   223.84      5.09      |
 8      0.00          |     0.00      0.00      |
 9      0.73          |    23.36      0.73      |
10     30.38          |   850.71     30.38      |
11      5.03          |    90.58      5.03      |
12      0.00          |     0.00      0.00      |
13      0.00          |     0.24      0.00      |
14      0.00          |     0.00      0.00      |
15      0.00          |     0.00      0.00      |
16      ----          |     0.00      ----      |
17      ----          |     0.00      ----      |
18  --------          |  --------  --------     |
19     41.24          |  1188.73     41.24      |
20 ----------------------------------------     |
21                    |      261                |
22                    |     1335                |
23                    |     2201                |
24                    |    0.839                |
25                    |    0.000                |
26                    |  --------               |
27                    |    0.839                |
28 ----------------------------------------
29 HEAT IN - HEAT OUT             -----------   |
30
31    -0.648
32
33
34 @sum({Up}.{End}{Up})~
35
36 /c~.{End}{Down}~
37
38 /c~{Right}{Right}~{Right}{Right}{Edit}{Home}{Del}~{Left}{Left}
39
40 {Rg(?)}
41
42 o \w
43 ppq
44                         alt s
45 agRCONST2~    ALT R  /ppfx~agppq
46
47                         ALT I
48 gppq                  /PPRH~AGLLR181~GPPQ
49
50
51 pq
52 gnpq
53 agRCONST2~AGpq
54
55
```

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
56	INSIDE SHELL GAS				-------------------OUTSIDE COMBTION GAS	------------											
57			T. F	T. K	OLD Tg	T 760	T. F	T. K	INSIDE SHELL GAS			OUTSIDE COMBTION GI			INSIDE SHELL GAS		
58	Tg =		696	642.0	642.2	Tgo =	2,201	1477.8									
59	Ts =		61	289.0		Two =	1,540	1110.6				Fwiwo =		1.00000			
60	Tw =		712	650.9		Twi =	1,081	855.8	Fsw =		1.00000	Fwowi =		0.77208	AS =		1.2791
61	Two-Twi =		468	260.00	<==	Tsh =	264	402.0	Fws =		0.30011	Fwowo =		0.22792	Aw =		4.2620
62					<==	260.0			Fwm =		0.69989				Ag =		5.5411
63	Twi-Tw =		369	204.91		650.91	<=== Tw								WS. m =		1.3999
64	Qg = 0	1588.32		24.677					Thrad =		1.57080						
65	Qs =			(350.134)		Qwo = 0		7	D =		1.97970	Lmo m =		0.75359	ps =		0.20
66	Qw = Qcd = Qg+Qs ===>			325.457		Qwi = Qcdwiw = Qw		(325.507)	Lm= 95*D*(1-FD)			2Lmo m =		1.50717	pw =		0.30
67	Qcdwiw = Qwi = Qw			325.456		Qgo =		341.022	Lm. m =		1.13	3Lmo m =		2.26076	pg =		0.00
68	Qs + Qw + Qg = 0			(0)		Qcdwosh =		15.522			1.32						
69	NEW Tg =		617	598.09		Qwi + Qwo + Qgo =		15.522	Lm. m =		1.12539	ri1 m =		0.98985	ABS =		0.80
70	NEW Ts =		(11)	248.88		hcvwS =	566.00		2Lm m =		2.25079	ro1. m =		1.29440	ABw =		0.70
71	OLD Ts =	237.30		387.39					3Lm m =		3.37618	ro2. m =		1.39600			
72	DEL Tg K =		(79)	-44.09		Tsho check K =		409.49				ro3. m =		1.39600	Es =		396
73	DEL Ts K =		224	124.46		Tw-Tg =		9	Lt. m =		0.91	rsh m =		1.41505	Ew =		10.177
74												Area3 =		8.01436	Eg =		9.632
75	TRgs1 =			0.7135		TRgowi1 =		0.7568				Ash =		8.12373			
76	TRgs2 =			0.5863		TRgowi2 =		0.6956									
77	TRgs3 =			0.5756		TRgowi3 =		0.6423				rwi. ft =		3.28095			
78	TRgw1 =			0.6117		TRgowo1 =		0.7888				ro2. ft =		4.58307			
79	TRgw2 =			0.4447		TRgowo2 =		0.7227				Lmo = 95*2*(ro1^2-					
80	TRgw3 =			0.5194		TRgowo3 =		0.6680	ri1 m =		0.98985	Lmo. m =		0.75			
81	TRgg1 =			0.6122		TRgogo1 =		0.8479	rwi =		0.99938						
82	TRgg2 =			0.5646		TRgogo2 =		0.7848									
83	TRgg3 =			0.5210		TRgogo3 =		0.7356									
84									Awi =		5.73736				sigma =		0.00
85	ABg1 =			0.39		ABgo1 =		0.15				kw1. W/m*		0.28818			
86	ABg2 =			0.05		ABgo2 =		0.06	kwi. W/m**		3.02594	kw2. W/m*		0.43228	OUTSIDE COMBTION GAS		
87	ABg3 =			0.04		ABgo2 =		0.05							Awi =		5.73736
88	TRg11=(ABg2+ABg3*(Fww*			0.153		TRgo11=(ABgo2+ABgo		0.505				moles tol		41.24	Awo =		7.43108
89	EMg =			0.39		EMgo =		0.15				Pco2 =		0.123	Ago =????		13.1684
90	ABg11 =			0.85		ABgo11 =		0.50				PH2O =		0.122	ABwi =?????		0.70
91															ABwo =?????		0.80
92	EMS =			0.80		EMwi =		0.70				PCO2 + PH		0.245	pwi =		0.30
93	EMw =			0.70		EMwo =		0.80				******************			pwo =		0.20
94	Thi =			90.00					******************			hcdwosh =1/[(2*@PI*ro3)*[(ro2pgo =					0.00
95	D. m =			1.98		Do. m =		2.59	hcdwiw = 1/((2*@PI*(rwi+ri1)/2			=		2.73324			
96	F/D =			0.146		Lo. m =		9.14	=		318	hrsha = sigma*Emsh*(Tsh*Tsh*Tsh*Tsh-Ta*Ta*Ta*Ta)					
97	L. m =			9.14		% excess air =		10.00	hrwigo = sigma*Emsh*(Tgo^4-Twi			=		6.95709			
98	Pwat =			0.88		(PH2O+Pco2)*Lmo =		0.185	=		270						
99	+PWAT*Lm =			0.9897		(PH2O+Pco2)*Lmo2 =		0.370				Tsh check(hcdwosh*Area3*Two+Ash*hcvsha*Ta+Ash*hrs					
100	+PWAT*Lm*2 =			1.9794		(PH2O+Pco2)*Lmo3 =		0.555	Twi check (+Awi*(hcvwigo+hrwigo)*Tgo+((A					409			
101	+PWAT*Lm*3 =			2.9691							708						
102						hcvgowi. W/m^2 K =		5.00				Qcdwosh = Qcvsha +					
103	moles H2O =			111.1		hcvgowo. W/m^2 K =		5	Qcdwiw = Qcvwigo +			Qcdwosh =Area3*hcdwosh*(Two-Tsh)					
104	moles total =			126.3		hcvsha W/m^2 K =		10	Qcdwiw = ((Awi+Aw)/2)*hcdwiw*(Twi-Tw)					15522			
105	Tgo. F =		2,201	1478		hrsha. W/m^2 K =		7			325456						
106	hcvws W/m^2 K =			566								Qcvsha = Ash*hcvsha*(Tsh-Ta)					
107	hcvgs. W/m^2 K =			50		ins1. in. =		4.0	Qcvwigo = Awi*hcvwigo*(Tgo-Twi)					8449			
108	hcvgw W/m^2 K =			10		ins2. in. =		0.0			17842						
109	hcvwigo. W/m^2 K =			5		shell. in =		0.6				Qrsha = Ash*hrsha*(Tsh-Ta)					
110	hrwgo. W/m^2 K =?????			????????????		kA1. BTU/hr*ft**2*		2.0	Qrwigo = Awi*hrwigo*(Tgo-Twi)					5878	Ewi =		30.415

```
        V        W        X        Y        Z        AA       AB       AC     AD       AE       AF       AG       AH       AI       AJ       AK       AL       AM       AN A     AP
-- ----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
56 Tgo  R =  2660 00 EmGo =     0 152 EmGo2 =    0 22 EmGo3 =    0 26 CsoG =    0 04         EmG CSO          PL CSO                                                      alt x
57 Twi  R =  1540 45 ABCwi1 =   0 243 ABHS1 =    0 13 ABCS1 =    0 12 Cso1 =    0 04     a =  0 0211     a =  0 0211          0 0150                               /(xvx^x^(^
58 Two  R =  1999 09 ABCwo1 =   0 211 ABHS2 =    0.18 ABCS2 =    0 15 Cso2 =    0 06     b =  0 0411     b =  0 0411          0 0583
59                   ABCwi2 =   0.304 ABHS3 =    0 22 ABCS3 =    0 16 Cso3 =    0 08     c = -0.0053     c = -0.0053         -0 0120                                    alt y
60 Plo1 ft =    0 30 ABCwo2 =   0.277 ABHW1 =    0 10 ABCW1 =    0 12                 0 6071  0 0441  0.6071  0.0441 PL1                                        (Golo)\y^(
61 Plo2 ft =    0.61 ABCwi3 =   0.358 ABHW2 =    0 15 ABCW2 =    0 14                 1 2143  0 0632  1 2143  0 0632 PL2
62 Plo3 ft =    0 91 ABCwo3 =   0.332 ABHW3 =    0 19 ABCW3 =    0 17                 1 8214  0 0784  1 8214  0 0784 PL3                                        (Golo)xx^/
63
64 Tg   R =  1155 60 ABHS1 =    0 287 ABHW1 =   0.388 EmG =     0 388
65 Ts   R =   520 20 ABHS2 =    0 414 ABHW2 =   0.555 EmG2 =    0 44                                                                                          PAUX LB/HR
66 Tw   R =  1171 62 ABHS3 =    0 424 ABHW3 =   0 481 EmG3 =    0 48                                                                                          HEAT IN =
67                                                                                                                                                            INSIDE SHE
68 PL1. ft =    3 25 PL1*Ts/Tg    1 46 PL1*Tw/Tg   3 29
69 PL2. ft =    6 50 PL2*Ts/Tg    2.93 PL2*Tw/Tg   6.59                                                                                                      Tg =
70 PL3. ft =    9 75 PL3*Ts/Tg    4 39 PL3*Tw/Tg     10                                                                                                      Ts =
71                                                                                                                                                            Tw =
72 --------- -------- -------- -------- -------- -------- -------- -------- ----------------------------------------------------------------------------    Two-Twi =
73 H2O        500 00  1000 00  1500 00  2000 00  2500 00  3000 00  3500 00 ******* 750 00
74 a            0 13     0 08     0 06     0 04     0.03     0 02     0 01    0 01    0 09                                                                     Twi-Tw =
75 b            0 30     0 29     0 27     0.22     0 20     0 16     0.15    0 12    0 29                                                                     Qg = 0
76 c           -0 08    -0 08    -0 07    -0 05    -0 05    -0 04    -0 04   -0 03   -0 08                                                                     Qs =
77                                                                                                                                                            Qw' = Qcd
78           Y=Emg      X=T                                                                                                                                   Qcdwiw = Q
79       L=   0 30               Y=Emg     X=T      X^2      X^3      X^4     XY      X^2Y       N      A =     0 00    X=T  Y calc Y act=Eg                      Qs + Qw' +
80   500 00   0.21    500 00     0 21    500 00 ************************105 00 52501 52    1 00      B =    -0 00  500 00    0 20    0 21                          NEW Tg =
81   750 00   0 18    750 00     0 18    750 00 ************************131 30 98478 55    1 00      C =  4400 00 1000 00    0 16    0 16                          NEW Ts =
82  1000.00   0 16   1000 00     0 16   1000 00 ************************159.92 *********   1.00      D =     0 21 1500 00    0 13    0.13                          OLD Ts =
83  1500 00   0 13   1500 00     0 13   1500 00 ************************201 86 *********   1 00      E = ********* 2000 00  0 11    0.11                          DEL Tg. K
84  2000.00   0 11   2000 00     0 11   2000.00 ************************213 71 *********   1.00                    2500.00  0 08    0 08                          DEL Ts. K
85  2500.00   0 08   2500 00     0.08   2500.00 ************************207.11 *********   1.00      a =     0 24 3000.00    0 06    0.07                          ----------
86  3000.00   0 07   3000 00     0 07   3000 00 ************************195.56 *********   1.00      b =    -0 00 3500.00    0 05    0.05                          PAUX LB/HR
87  3500.00   0 05   3500 00     0.05   3500 00 ************************180.88 *********   1.00      c =     0.00 4000.00    0 04    0.04                          HEAT IN =
88  4000.00   0.04   4000 00     0.04   4000.00 ************************163.09 *********   1.00                    2660.00  0.08                                  INSIDE SHE
89         --------- -------- -------- -------- -------- -------- -------- ------ -------- --------
90          500.00                1 03 18750.00 *****************************************    9.00                                                                 Tg =
91                                  Y         X      X#2      X#3      X#4     XY     X#2Y       N         EmGo1 = (EGCO21+ECH2O1)(1-Cso1)                     Ts =
92                                                                                                                    0.15                                      Tw =
93                                                                                                                                                              Two-Twi =
94 CO2        500.00  1000 00  1500 00  2000.00  2500.00  3000.00  3500 00 *******
95 --------- -------- -------- -------- -------- -------- -------- -------- --------                                                                           Twi-Tw =
96 a            0.08     0 07     0 08     0.07     0.06     0 04     0.04    0.03                                                                              Qg = 0
97 b            0.11     0.10     0.10     0.12     0.11     0 10     0 08    0 07                                                                              Qs =
98 c           -0.03    -0 03    -0.03    -0.03    -0.03    -0.02    -0 02   -0.02                                                                              Qw' = Qcd
99                                                                                                                                                              Qcdwiw = Q
100          Y=Emg      X=T                                                                                                                                     Qs + Qw' +
101      L=   0.30               Y=Emg     X=T      X^2      X^3      X^4     XY      X^2Y       N      A =     0 00    A =     0 00    X=T  Y calc Y act=Eg      NEW Tg =
102  500.00   0 11    500.00     0.11    500.00 ************************ 57 31 28657.25    1.00      B =    -0.00    B =    -0 00  500 00   0 11    0.11       NEW Ts =
103 1000.00   0.09   1000.00     0.09   1000 00 ************************ 94 14 94138.54    1.00      C =  2500.00    C =  6500.00 1000 00   0.10    0.09       OLD Ts =
104 1500.00   0 10   1500 00     0 10   1500 00 ************************155.53 *********   1 00      D =     0.11    D =     0 16 1500 00   0.10    0.10       DEL Tg. K
105 2000 00   0.10   2000 00     0 10   2000 00 ************************207 35 *********   1 00      E = *********   E = ********* 2000 00  0 11    0 10       DEL Ts. K
106        --------- -------- -------- -------- -------- -------- -------- ------ -------- --------                                 2500 00   0 09    0 09       ----------
107         500.00                0 42  5000 00 ************************514 33 *********   4 00      a =     0.14    a =     0 20 3000.00   0.07    0 07       PAUX LB/HR
108                                  Y        X      X#2      X#3      X#4     XY     X#2Y       N      b =    -0.00    b =    -0 00 3500.00   0 06    0 06       HEAT IN =
109                                                                                                  c =     0.00    c =     0 00 4000.00   0.05    0 05       INSIDE SHE
110      L=   0.30               Y=Emg     X=T      X^2      X^3      X^4     XY      X^2Y       N                                     2660 00   0 08
```

```
          AQ        AR        AS        AT        AU        AV        AW        AX        AY        AZ
-- -----------------------------------------------------------------------------------------------------
56
57 {GoTo}xx~/Iccex~{PgDn}\-~/c~ {Right}{Right}{Right}{Right}{Right}{Right}{Right}~{Down}/rndxx~/rncxx~~{GoTo}tQS1~{Left}{End}{Down}{Right}{End}{Up}{Down}{?}-QS+3 414~{?}~{GoTo}c~{Right}{Right}{Down}
58
59
60 Down}{Down}{Down}{Down}{Down}/rncy~{BS}.{Right}{Right}{Right}{Right}{Right}{Right}{Right}{Right}{Right}{End}{Down}{Left}{Left}{End}{Up}{Right}{?}~/ppry~agppq~{GoTo}c~
61
62 rndxx~{PgUp}{Up}{?}/rncxx~~{GoTo}c~{Right}{Right}{Down}{Down}{Down}{Down}
63
64
65  =              70 00
66      1 355         HEAT OUT =       1 481            DELTA H =  -0 1263
67 LL GAS      --------------------OUTSIDE COMBTION GAS ------------------
68     T. F          T. K    OLD Tg      1.760     T. F          T. K |
69        603      590 0      400 0 Tgo =          2.101      1422 2 |
70      1.144      891 0            Two =          1.701      1200.1 |
71      1.340      999 9 |          Twi =          1.547      1114 7 |
72        157      87 20 | <==      Tsh =            293       418.0 |
73                       |    <==       87 2                         |
74        207     114 76 |             999 88    <=== Tw             |
75    1588 32  (104.884)|                                            |
76              (77.384)|          Qwo = 0                      (19)|
77 = Qg+Qs ==    182 268 *          Qwi = Qcdwiw = Qw      (182.179)|
78 wi = Qw       182.268 *          Qgo =                    199,330 |
79  Qg = 0             0 |          Qcdwosh =                 17,132 |
80        601     588.84 *          Qwi + Qwo + Qgo =         17,132 |
81      1.146     891 68 *           hcvWS =      566.00             |
82    1200 60     922.56 |                                           |
83        340     188 84 |          Tsho check, K =           418.51 |
84         55      30.54 |            Tw-Tg =                    410 |
85 --------------------------------------------------------------------
86  =              70 00
87      1 355         HEAT OUT =       1.503            DELTA H =  -0 1486
88 LL GAS      --------------------OUTSIDE COMBTION GAS ------------------
89     T. F          T. K    OLD Tg      1.760     T. F          T. K |
90        824      713.0      588.8 Tgo =          2,101      1422.2 |
91      1,067      848 0            Two =          1,688      1193 0 |
92      1,310      983.0 |          Twi =          1,524      1101.8 |
93        168      93.10 | <==      Tsh =            293       418.0 |
94                       |    <==       93.1                         |
95        214     118.78 |             983.08    <=== Tw             |
96    1588.32   (70.948)|                                            |
97             (117.705)|          Qwo = 0                         44 |
98 = Qg+Qs ==    188.653 *          Qwi = QCdwiw = Qw      (188.922)|
99 wi = Qw       188.653 *          Qgo =                    205,855 |
100  Qg = 0           (0)|          Qcdwosh =                 16,977 |
101       826     714.31 *          Qwi + Qwo + Qgo =         16,977 |
102     1.062     845.23 *           hcvWS =      566.00             |
103   1145 63     892 02 |                                           |
104       226     125 47 |          Tsho check, K =           417.56 |
105       139      76 99 |            Tw-Tg =                    270 |
106 --------------------------------------------------------------------
107  =              70 00
108     1 355         HEAT OUT =       1 546            DELTA H =  -0 1912
109 LL GAS      --------------------OUTSIDE COMBTION GAS ------------------
110    T. F          T. K    OLD Tg      1.760     T. F          T. K |
```

```
  A        B        C        D         E        F        G        H         I        J        K        L        M        N        O        P        Q        R        S    T    U
-- -----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
111 |          kwi  BTU/hr*ft**2*F/in          21 |       kk2  BTU/hr*ft**2*          3 0 |                        963847 |                               |          Ewo =          86.263 |
112 |          shell  in =                      0 4 |       Emsh =                      0 7 |                               |         QcvshoQrs     14326 |          Ego =         270 407 |
113 |          Emsh =                           0 7 |       Ta =                        298 |             Qcvwigo+Qr  981689 |                               |          sigma =          0 00 |
114 |                                               |                                     |                               |                               |                                 |
115 -------------------------------------------------------------------------------------------------     ---------------------------------------------------------------------------------------|
116 BASIS : GAS ENTHALPY                                              Tg =       695 60            Tg IN =    260 00 CROSSECT  AR     0 280
117 ---------------------                                               Cp          Tg                   Tg           = ((D/2)^2((THRAD/2-@COS(THRAD/2)*@SIN(THRAD/2))
118 FEED LB/HR              20000 00   O2 LB/HR        84        BTU/LB*F      BTU/HR               BTU/HR             % FILL =      0 10         A             B              C
119       % H2O                10 00%  N2 LB/HR       358                         OUT                   IN             SOLID BED VO    2 56
120 Cp BTU/LB*F. DRY            0 27 LBS H2O/HR      2000                                                                    FT^3 =    90 23
121 F/D FILL RATIO             10 00 N2+AIR FT3/     6300      O2     0 2471      13.180  0 2413      4.049                                       0 24        0.00         -0.00          O2
122 N2 GAS  FT3/MIN            10 00  GAS LB/HR       442      N2     0 2531      57.546  0.2473     17.695           CROSSECT  AR    2.80       0 24        0 00         -0 00          N2
123 LEAK AIR  FT3/MIN          95.00 TOTAL LB/HR     2442     H2O     0 4664   2 712 932  0.4488 2.299.528           FREEBOARD VO   25.57       0 44        0.00         -0.00         H2O
124 DENSITY. LB/FT3             0 07  MOLES H2O       111                      -----------        ----------                  FT^3 =   902.99
125 MOLAR VOL  FT3/MOL        413 60  MOLES GAS     15.23                    2 783.658            2.321.272
126     Tair  F                70 00  MOL % H2O      0.88 DEL H GAS  BTU/HR    462387                                  AVG  DENSITY OF SOLID BED. LB/FT^3 =            100 00
127 HEAT OF VAPOR  BTU/LB    1054 00                                  WATTS    135438             Cp IN =   1 7937 SOLID FEED RATE. FT^3/HR =                        200 00
128 hcvws BTU/FT^2*F =         99 65                     BTU/F =             1061 49            Cp OUT =   4 7535 RESIDENCE TIME FOR SOLID BED. HR =                0 451
129                                                      DEL Tg. K =          -44 09
130 BASIS  SOIL ENTHALPY               BASIS  SOIL ENTHALPY                           QTg BTU/  2783658                VOLUME OF GAS. FT^3/HR =                         97825
131 ----------------------             -----------                                    Qg BTU/H     84247                RESIDENCE TIME FOR GAS. HR =                   0 00923
132 SOIL DRY BASIS. LB2/HR   18000 00 Qs BTU/HR = 7932979           6737622          ------------------
133 BTU/HR*F =                4806 00 BTU TO 212F 4748328      1     350219          QTg' BTU  2699411
134 DEL Ts. K =               124 46 DEL IN BTU= 2108000      2     512669
135 EXIT SOLID TEMP  F =     1200 00 BTU < 212F= 1076651      3     681061          Tg'. K =    597 91
136 NEW Ts. K =               248 88 BTU > 212 =        0      4     838621          = Tg+DEL Tg
137 NEW Ts. F =               -12 02 BTU=212 F =        0      5     988982
138                      Ts < 212  DEL Ts.F=    224 02      6    1121706
139                      Ts > 212F  DEL Ts.F=     0.00      7    1130623
140                      Ts = 212F  DEL Ts.F=     0.00      8    1113741                       {Edit}{Home}{Right}/RNC{I}~~{I}/xg\z~
141                                                          9                                  INDIRECT FIRED KILN MODEL VALUES
142                               DEL Ts.C=    124.46      10                                                                                                    |
143                               BTU 60->212  730512                                                      Qwi = wi1Ewi + wi2Ewo + wi3Ego + hcvws(Two - Twi) + hcvgs(Tgo|
144                               BTU Ts->60  -346139                                                                                                            |
145          Qw = w1Es + w2Ew + w3Eg + hcvgw(Tg - Tw) - hcdwsh(Tw - Tsh)                                   Qwo = wo1Ewi + wo2Ewo + wo3Ego + hcvgowo(Tgo - Two) - hcdwosh|
146                                                                                                                                                           |
147          Qg = g1Es + g2Ew + g3Eg - hcvgs(Tg - Ts) + hcvgw(Tg - Tw)                                     Qgo = go1Ewi + go2Ewo + go3Ego - hcvguwi(Tgo - Twi) + hcvgowo|
148                                                                                                                                                           |
149                                                                                                                                                           |
150          Qs                                                                                            Qwi                                                          |
151          ****************************************  watts   BTU/HR                                      *************************************   watts     BTU/HR   |
152                                                                                                                                                           |
153 Es       s1          Ems*As                    1.023                           Ewi        wi1        EMwi*Awi                  4.0162                            |
154                2.00 -ABS*TRgs2*Fws*Fsw*pw*   -0.043                                              2 00 -ABwi*TRgowi2*Fwowi*F -0 3020                           |
155                3.00 -ABS*TRgs3*Fws*Fww*Fsw   -0.009                                              3.00 -ABwi*TRgowi3*Fwowi*F -0 0127                           |
156                4.00 -Fws*TRgs3*Fww*Fww*Fsw   -0.002                                              4 00 -Fwowi*TRgowi3*Fwowo* -0 0008                           |
157                5.00 -Fws*TRgs3*Fws*Fsw*Fsw   -0 001                                              5.00 -Fwowi*TRgowi3*Fwowi* -0.0185                           |
158 Qs => Qs                                   0.968      383     1.307           Qwi => Qwi                                     3.6822     111.994     382.346 |
159                                                                                                                                                           |
160 Ew       s2          -ABS*TRgw1*Fws*EMw*Aw  -0 4382                            Ewo        wi2        -ABwi*TRgowo1*Fwowi*E -2 5342                           |
161                2.00 -ABS*TRgw2*Fws*Fww*pw*  -0 0669                                              2.00 -ABwi*TRgowo2*Fwowi*F -0 1059                           |
162                3 00 -ABS*TRgw3*Fws*Fww*Fww  -0 0164                                              3.00 -ABwi*TRgowo3*Fwowi*F -0 0045                           |
163                4 00 -ABS*TRgw3*Fws*Fws*Fsw  -0 0067                                              4.00 -ABwi*TRgowo3*Fwowi*F -0.0994                           |
164                5.00 -Fws*TRgw3*Fww*Fww*Fww  -0 0043                                              5 00 -Fwowi*TRgowo3*Fwowo* -0 0003                           |
165                6.00 -2*Fws*TRgw3*Fws*Fww*F  -0.0035                                              6.00 -2*Fwowi*TRgowo3*Fwow -0.0129                           |
```

--	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
111	2500.00	0.09	2500.00	0.09	2500.00	********	********	********	220.51	*********	1.00									Tg =
112	3000.00	0.07	3000.00	0.07	3000.00	********	********	********	216.49	*********	1.00									Ts =
113	3500.00	0.06	3500.00	0.06	3500.00	********	********	********	202.39	*********	1.00									Tw =
114	4000.00	0.05	4000.00	0.05	4000.00	********	********	********	181.54	*********	1.00									Two-Twi =
115		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
116		500.00		0.26	13000.00	********	********	********	820.94	*********	4.00									Twi-Tw =
117				Y	X	X#2	X#3	X#4	XY	X#2Y	N									Qg = 0
118	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********		Qs =
119	---------	--------	--------	--------	--------	--------	--------	--------	------	--------										Qw' = Qcd
120	H2O15	500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	*******	750.00										Qcdwiw = Q
121	a	0.13	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.09										Qs + Qw' +
122	b	0.30	0.29	0.27	0.22	0.20	0.16	0.15	0.12	0.29										NEW Tg =
123	c	-0.08	-0.08	-0.07	-0.05	-0.05	-0.04	-0.04	-0.03	-0.08										NEW Ts =
124																				OLD Ts =
125		Y=Emg	X=T																	DEL Tg, K
126	L=	0.18		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg				DEL Ts, K
127	500.00	0.18	500.00	0.18	500.00	********	********	********	88.47	44233.91	1.00	B =	-0.00	500.00	0.17	0.18				----------
128	750.00	0.14	750.00	0.14	750.00	********	********	********	106.84	80132.17	1.00	C =	4400.00	1000.00	0.13	0.13				PAUX LB/HR
129	1000.00	0.13	1000.00	0.13	1000.00	********	********	********	128.01	*********	1.00	D =,	0.17	1500.00	0.10	0.10				HEAT IN =
130	1500.00	0.10	1500.00	0.10	1500.00	********	********	********	157.26	*********	1.00	E =	*********	2000.00	0.08	0.08				INSIDE SHE
131	2000.00	0.08	2000.00	0.08	2000.00	********	********	********	163.53	*********	1.00			2500.00	0.06	0.06				
132	2500.00	0.06	2500.00	0.06	2500.00	********	********	********	151.99	*********	1.00	a =	0.21	3000.00	0.05	0.05				Tg =
133	3000.00	0.05	3000.00	0.05	3000.00	********	********	********	140.32	*********	1.00	b =	-0.00	3500.00	0.03	0.04				Ts =
134	3500.00	0.04	3500.00	0.04	3500.00	********	********	********	123.35	*********	1.00	c =	0.00	4000.00	0.03	0.03				Tw =
135	4000.00	0.03	4000.00	0.03	4000.00	********	********	********	110.10	*********	1.00			1540.45	0.10					Two-Twi =
136		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
137		500.00		0.80	18750.00	********	********	********	********	*********	9.00	ABgst = (ABCO2+ABH2O)(1-CSO1)								Twi-Tw =
138				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.24						Qg = 0
139												ABCO2 = (EMCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts).65								Qs =
140														0.12						Qw' = Qcd
141	CO21	500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	*******			ABH2O = (EMH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts).45								Qcdwiw = Q
142	---------	--------	--------	--------	--------	--------	--------	--------	--------					0.13						Qs + Qw' +
143	a	0.08	0.07	0.08	0.07	0.06	0.04	0.04	0.03											NEW Tg =
144	b	0.11	0.10	0.10	0.12	0.11	0.10	0.08	0.07			Tg =	2660.00	PL1*Ts/Tg		0.18				NEW Ts =
145	c	-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02			Ts =	1540.45	CSO1 =		0.04				OLD Ts =
146																				DEL Tg, K
147		Y=Emg	X=T																	DEL Ts, K
148	L=	0.18		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg		----------
149	500.00	0.10	500.00	0.10	500.00	********	********	********	51.39	25696.16	1.00	B =	-0.00	B =	-0.00	500.00	0.10	0.10		PAUX LB/HR
150	1000.00	0.08	1000.00	0.08	1000.00	********	********	********	82.93	82934.36	1.00	C =	2500.00	C =	6500.00	1000.00	0.09	0.08		HEAT IN =
151	1500.00	0.09	1500.00	0.09	1500.00	********	********	********	139.53	*********	1.00	D =	0.10	D =	0.14	1500.00	0.09	0.09		INSIDE SHE
152	2000.00	0.09	2000.00	0.09	2000.00	********	********	********	180.95	*********	1.00	E =	*********	E =	*********	2000.00	0.09	0.09		
153		---------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500.00	0.08	0.08		Tg =
154		500.00		0.37	5000.00	********	********	********	454.80	*********	4.00	a =	0.12	a =	0.17	3000.00	0.06	0.06		Ts =
155				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.05	0.05		Tw =
156												c =	0.00	c =	0.00	4000.00	0.04	0.04		Two-Twi =
157	L=	0.18		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1540.45	0.09			
158	2500.00	0.08	2500.00	0.08	2500.00	********	********	********	188.40	*********	1.00									Twi-Tw =
159	3000.00	0.06	3000.00	0.06	3000.00	********	********	********	183.39	*********	1.00									Qg = 0
160	3500.00	0.05	3500.00	0.05	3500.00	********	********	********	170.42	*********	1.00									Qs =
161	4000.00	0.04	4000.00	0.04	4000.00	********	********	********	151.66	*********	1.00									Qw' = Qcd
162		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									Qcdwiw = Q
163		500.00		0.22	13000.00	********	********	********	693.87	*********	4.00									Qs + Qw' +
164				Y	X	X#2	X#3	X#4	XY	X#2Y	N									NEW Tg =
165	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********				NEW Ts =

```
             AQ         AR         AS         AT         AU         AV         AW         AX         AY         AZ
-- -----------------------------------------------------------------------------------------------------------
111         941      778 0     714 3 Tgo =         2.101     1422 2 |
112         943      779 0           Two =         1.663     1179 3 |
113       1 249      949 2 |         Twi =         1.478     1076 1 |
114         190      105 30 | <==    Tsh =           288      415 0 |
115                         |    <==      105 3                     |
116         228      126 94 |             949 19   <=== Tw          |
117     1588 32    (37 943)|                                        |
118                (163.678)|         Qwo = 0                    10 |
119 = Qg+Qs ==    201 621 *          Qwi = Qcdwiw = Qw    (201.612)|
120 wi = Qw       201.621 *          Qgo =                218.345 |
121  Qg = 0           (0)|           Qcdwosh =             16.743 |
122         946      780 79 *        Qwi + Qwo + Qgo =     16 743 |
123         946      780 64 *         hcvwS =      566.00           |
124     1062 02      845 56 |                                       |
125         120       66 48 |        Tsho check. K =       416 33 |
126         255      141 59 |           Tw-Tg =               171 |
127 -----------------------------------------------------------------------
128  =                70 00
129       1 355        HEAT OUT =       1 598           DELTA H =  -0 2435
130 LL GAS     ---------------------OUTSIDE COMBTION GAS ------------------
131     T  F          T  K    OLD Tg      1 760     T. F         T. K |
132         984      802 0     780 8 Tgo =         2 101     1422 2 |
133         801      700 0           Two =         1 633     1162 2 |
134       1,171      905 6 |         Twi =         1 417     1042 4 |
135         220      122 30 | <==    Tsh =           288      415 0 |
136                         |    <==      122 3                     |
137         246      136 80 |             905 60   <=== Tw          |
138     1588.32    (12.349)|                                        |
139                (204.927)|         Qwo = 0                    13 |
140 = Qg+Qs ==    217.276 *          Qwi = Qcdwiw = Qw    (217.287)|
141 wi = Qw       217.275 *          Qgo =                233.643 |
142  Qg = 0           (0)|           Qcdwosh =             16.369 |
143         985      802 35 *        Qwi + Qwo + Qgo =     16.369 |
144         800      699 76 *         hcvwS =      566 00           |
145      945.75      780.97 |                                       |
146          39       21.56 |        Tsho check. K =       414.04 |
147         400      222.46 |           Tw-Tg =               104 |
148 -----------------------------------------------------------------------
149  =                70.00
150       1.355        HEAT OUT =       1 664           DELTA H =  -0 3096
151 LL GAS     ---------------------OUTSIDE COMBTION GAS ------------------
152     T. F          T. K    OLD Tg      1.760     T. F         T. K |
153         964      790.6     802 4 Tgo =         2.101     1422.2 |
154         626      603.0           Two =         1.593     1140 1 |
155       1.063      846.0 |         Twi =         1.332      995.3 |
156         266      147.70 | <==    Tsh =           288      415.0 |
157                         |    <==      147 7                     |
158         269      149.31 |             845.99   <=== Tw          |
159     1588 32       6.417 |                                       |
160                (243 565)|         Qwo = 0                     7 |
161 = Qg+Qs ==    237.148 *          Qwi = Qcdwiw = Qw    (237.131)|
162 wi = Qw       237.148 *          Qgo =                253.006 |
163  Qg = 0           (0)|           Qcdwosh =             15.882 |
164         965      791 13 *        Qwi + Qwo + Qgo =     15.882 |
165         627      603.64 *         hcvwS =      566.00           |
```

	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q
166	Qs => Qw					-0 5360	15 4551	(18 623)	Qwi => Qwo					-2 7572	(237.842)	(811 992)
167																
168	Eg	s3		-ABS*Emg*AS		-0 397			Ego	wi3		-ABwi*Emgo*Awi		-0 6107		
169			2 00	-ABS*Fws*pw*TRgl1*Emg*		-0 018					2 00	-ABwi*Fwowi*pwo*TRgo1		-0 0616		
170	Qs => Qg					-0.415	(3.998)	(13.648)	Qwi => Qgo					-0.6724	(181.817)	(620.722)
171																
172		hcvws		+hcvws*(THIrad*D/2)*(T		318489	(318 489)	*********		hcvws		+hcvwowi*(THIrad*D/2)*(Two-Twi			(0)	0
173		hcvgs		+hcvgs*As*(Tg-Ts)		22575	(22 575)	(77 072)		hcvgs		+hcvgowi*Awi*(Tgo-Twi		17842	(17.842)	(60 914)
174							*********							17842	***********	
175	Qs =>						(350 134)	*********	Qwi =>						(325.507)	(1,111 281)
176																
177												5 7374	1 0000	7 4311		
178		Qw			1.00					Qw		5 7374	0 7721	5.7374		
179		**								**						
180																
181		w1		-ABw*TRgs1*FSw*EMS*AS		-0 5110				wo1		-ABwo*TRgowi1*Fwiwo*E		-2.4315		
182			2 00	-ABw*TRgs2*Fww*FSw*pw*		-0 0882					2 00	-ABwo*TRgowi2*Fwowo*F		-0.1019		
183	Es		3.00	-ABw*TRgs3*Fww*Fww*FSw		-0 0182			Ewi		3 00	-ABwo*TRgowi3*Fwowo*F		-0 0043		
184			4 00	-ABw*TRgs3*Fws*FSw*FSw		-0 0074					4 00	-ABwo*TRgowi3*Fwowi*F		-0 0956		
185			5 00	-Fww*TRgs3*Fww*Fww*FSw		-0 0055					5 00	-Fwowo*TRgowi3*Fwowo*		-0 0002		
186			6 00	-2*Fww*TRgs3*Fws*FSw*F		-0 0045					6.00	-2*Fwowo*TRgowi3*Fwow		-0 0109		
187	Qw => Qs					-0 6347	(251)	(857)	Qwo => Qwi					-2.6444	(80.430)	(274.587)
188																
189		w2		+EMw*Aw		2 983				wo2		+EMwo*Awo		5 9449		
190	Ew		2 00	-ABw*TRgw1*Fww*EMw*Aw		-0 894			Ewo		2 00	-ABwo*TRgowo1*Fwowo*E		-0 8550		
191	? * Fww		3 00	-ABw*TRgw2*Fww*Fww*pw*		-0 136			? * Fww		3 00	-ABwo*TRgowo2*Fwowo*F		-0.0357		
192			4 00	-ABw*TRgw2*Fws*FSw*ps*		-0 056					4 00	-ABwo*TRgowo2*Fwowi*F		-0 7961		
193			5 00	-ABw*TRgw3*Fww*Fww*Fww		-0 033					5.00	-ABwo*TRgowo3*Fwowo*F		-0 0015		
194			6 00	-2*ABw*TRgw3*Fws*Fww*F		-0 027					6 00	-2*ABwo*TRgowo3*Fwowi		-0 0671		
195			7 00	-Fww*TRgw3*Fww*Fww*Fww		-0 010					7 00	-Fwowo*TRgowo3*Fwowo*		-0 0001		
196			8 00	-2*Fww*TRgw3*Fws*Fww*F		-0 008					8 00	-2*Fwowo*TRgowo3*Fwow		-0 0038		
197			9.00	-FSw*TRgw3*Fww*Fww*Fws		-0 004					9.00	-Fwiwo*TRgowo3*Fwowo*		-0.0019		
198			10.00	-FSw*TRgw3*Fws*Fws*FSw		-0 002					10 00	-Fwiwo*TRgowo3*Fwowi*		-0 0426		
199	Qw => Qw					1 812	18.444	62.967	Qwo => Qwo					4 1410	357.213	1,219.525
200																
201	Eg	w3		-ABw*Emg*Aw		-1 157			Ego	wo3		-ABwo*Emgo*Awo		-0 9041		
202			2.00	-ABw*Fww*pw*TRg11*Emg*		-0 037					2.00	-ABwo*Fwowo*pwo*TRgo1		-0 0208		
203			3.00	-ABw*FSw*ps*TRg11*Emg*		-0 011					3.00	-ABwo*Fwiwo*pwi*TRgo1		-0 1057		
204	Qw => Qg					-1.205	(11.604)	(39.617)	Qwo => Qgo					-1 0305	(278.656)	(951.330)
205																
206		hcvws		+hcvws*(THIrad*D/2)*(T		318489	318.489	*********		hcvws		+hcvwowi*(THIrad*D/2)*(Two-Twi			0	0
207		hcvgw		+hcvgw*Aw*(Tg-Tw)		-379	379			hcvgw		+hcvgowo*Awo*(Tgo-Two		13642	(13.642)	
208		hcdwsh		+hcdwiw*((Awi+Aw)/2)*(		-325456	<=======	NOT ADDED		hcdwsh		+hcdwosh*Area3*(Two-T		15522	15.522	
209							*********							29165	***********	
210	Qw =>						325.457	*********	Qwo =>						7	25
211																
212		Qg								Qg						
213		**								**						
214																
215	Es	g1		-(1-TRgs1)*FSw*EMS*AS		-0 293			Ewi	go1		-(1-TRgowi1)*Fwiwo*Em		-0 9767		
216			2.00	-(TRgs1-TRgs2)*FSw*pw*		-0 039					2.00	-(TRgowi1-TRgowi2)*Fw		-0 0492		
217			3.00	-(TRgs2-TRgs3)*Fww*FSw		-0 001					3 00	-(TRgowi2-TRgowi3)*Fw		-0 0019		
218			4 00	-(TRgs2-TRgs3)*Fws*FSw		-0 000					4.00	-(TRgowi2-TRgowi3)*Fw		-0 0099		
219	Qg => Qs					-0 333	(132)	(450)	Qgo => Qwi					-1 0378	(31 564)	(107.759)
220																

Row		V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
166																					OLD Ts =
167	H2O1W		500 00	1000 00	1500 00	2000 00	2500.00	3000 00	3500 00	*******	750 00										DEL Tg. K
168	a		0 13	0 08	0 06	0 04	0 03	0 02	0 01	0 01	0 09										DEL Ts. K
169	b		0 30	0 29	0 27	0 22	0.20	0 16	0 15	0 12	0 29										----------
170	c		-0 08	-0 08	-0.07	-0 05	-0.05	-0 04	-0 04	-0 03	-0 08										PAUX LB/HR
171																					HEAT IN =
172			Y=Emg	X=I																	INSIDE SHE
173		L =	0 23		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	X=I	Y calc	Y act=Eg				
174		500 00	0 19	500 00	0 19	500 00	**************************			95 40	47699 99	1 00	B =	-0 00	500 00	0 18	0 19				Tg =
175		750 00	0 16	750 00	0 16	750 00	**************************			117 11	87830 49	1 00	C =	4400 00	1000 00	0 15	0 14				Ts =
176		1000 00	0 14	1000 00	0 14	1000.00	**************************			141 39	*********	1 00	D =	0 19	1500 00	0 12	0.12				Tw =
177		1500 00	0 12	1500 00	0 12	1500.00	**************************			175.94	*********	1 00	E =	*********	2000 00	0 09	0.09				Two-Twl =
178		2000 00	0 09	2000 00	0.09	2000 00	**************************			184 50	*********	1 00			2500 00	0.07	0.07				
179		2500 00	0 07	2500 00	0 07	2500.00	**************************			175.04	*********	1.00	a =	0 22	3000 00	0 05	0.05				Twl-Tw =
180		3000 00	0 05	3000 00	0 05	3000.00	**************************			163.38	*********	1 00	b =	-0.00	3500 00	0 04	0.04				Qg = 0
181		3500.00	0 04	3500 00	0.04	3500 00	**************************			147 41	*********	1 00	c =	0.00	4000.00	0 03	0.03				Qs =
182		4000 00	0 03	4000 00	0 03	4000 00	**************************			132 21	*********	1.00			1999 09	0 09					Qw' = Qcd
183			---------	--------	--------	--------	--------	--------	--------	------	--------	--------									Qcdwlw = Q
184			500 00		0 90	18750 00	***					9 00	, ABgwl = (ABCO2+ABH2O)(1-CSOI)								Qs + Qw' +
185					Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.21						NEW Tg =
186													ABCO2 = (EMCO2 @ Tw. P*L*Tw/Tg)*(Tg/Tw).65								NEW Ts =
187															0 12						OLD Ts =
188	CO2I		500 00	1000 00	1500.00	2000 00	2500.00	3000.00	3500 00	*******			ABH2O = (EMH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw).45								DEL Tg. K
189	---------		--------	--------	--------	--------	--------	--------	--------	--------					0. 10						DEL Ts. K
190	a		0 08	0 07	0 08	0.07	0.06	0.04	0 04	0 03											----------
191	b		0 11	0 10	0 10	0 12	0 11	0 10	0 08	0 07			Tg =	2660 00	PLI*Tw/Tg		0 23				PAUX LB/HR
192	c		-0 03	-0 03	-0.03	-0 03	-0.03	-0 02	-0 02	-0 02			Tw =	1999.09	CSOI =		0.04				HEAT IN =
193																					INSIDE SHE
194			Y=Emg	X=I																	
195		L =	0 23		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0.00	X=T	Y calc	Y act=Eg		Tg =
196		500.00	0.11	500 00	0 11	500 00	**************************			53 89	26942.90	1.00	B =	-0 00	B =	-0 00	500.00	0.11	0 11		Ts =
197		1000 00	0 09	1000.00	0 09	1000.00	**************************			87 63	87633 53	1.00	C =	2500 00	C =	6500.00	1000.00	0 09	0 09		Tw =
198		1500.00	0.10	1500.00	0 10	1500.00	**************************			146 23	*********	1.00	D =	0.10	D =	0.15	1500 00	0.09	0.10		Two-Twl =
199		2000 00	0. 10	2000 00	0. 10	2000.00	**************************			192 02	*********	1.00	E =	*********	E =	*********	2000 00	0 10	0 10		
200			---------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500.00	0.08	0 08		Twl-Tw =
201			500.00		0. 39	5000.00	**************************			479 78	*********	4 00	a =	0 13	a =	0 18	3000 00	0 07	0 07		Qg = 0
202					Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0 00	3500.00	0 05	0 05		Qs =
203													c =	0 00	c =	0.00	4000.00	0 04	0 04		Qw = Qcd
204		L =	0.23		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1999.09	0 10			Qcdwlw = Q
205		2500 00	0.08	2500 00	0 08	2500.00	**************************			201 85	*********	1.00									Qs + Qw' +
206		3000.00	0.07	3000.00	0 07	3000.00	**************************			197.23	*********	1 00									NEW Tg =
207		3500 00	0 05	3500 00	0.05	3500.00	**************************			183 79	*********	1.00									NEW Ts =
208		4000.00	0.04	4000.00	0.04	4000.00	**************************			164.15	*********	1.00									OLD Ts =
209			---------	--------	--------	--------	--------	--------	--------	------	--------	--------									DEL Tg. K
210			500.00		0. 24	13000 00	**************************			747.02	*********	4.00									DEL Ts. K
211					Y	X	X#2	X#3	X#4	XY	X#2Y	N									----------
212	**																				PAUX LB/HR
213																					HEAT IN =
214	H2O2S		500.00	1000.00	1500 00	2000.00	2500 00	3000.00	3500 00	*******	750 00										INSIDE SHE
215	a		0 13	0 08	0 06	0 04	0.03	0 02	0 01	0.01	0 09										
216	b		0 30	0 29	0 27	0.22	0 20	0 16	0 15	0 12	0 29										Tg =
217	c		-0 08	-0 08	-0 07	-0.05	-0.05	-0 04	-0 04	-0 03	-0.08										Ts =
218																					Tw =
219			Y=Emg	X=I																	Two-Twl =
220		L =	0 35		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=I	Y calc	Y act=Eg				

```
          AQ        AR        AS        AT        AU        AV        AW        AX        AY        AZ
-- ------------------------------------------------------------------------------------------------------
166    800 17    700 10 |                                  |
167      120)    -11 22 |         Tsho check  K =    411 06 |
168       573    318 58 |           Tw-Tg =              55 |
169 ----------------------------------------------------------------------
170  =              70 00
171     1 355         HEAT OUT =       1 737           DELTA H =  -0 3820
172 LL GAS       -------------------OUTSIDE COMBTION GAS -----------------
173    T  F           T  K     OLD Tg     1.760     T. F         T  K |
174       901     756 0     791 1 Tgo =         2.101    1422 2 |
175       430     494 0           Two =         1.548    1115 0 |
176       933     773.5 |         Twi =         1.226     936 4 |
177       328    182.30 | <==     Tsh =           279     410 0 |
178                     |    <==       182.3                    |
179       293    162.89 |           773.52   <=== Tw            |
180   1588 32    19.417 |                                       |
181             (278.136)|        Qwo = 0                    50 |
182 = Qg+Qs ==  258.719 *         Qwi = Qcdwiw = Qw   (258.838)|
183 wi = Qw     258.719 *         Qgo =                 274.232 |
184  Qg = 0           0 |         Qcdwosh =              15.444 |
185       903    757 00 *         Qwi + Qwo + Qgo =      15.444 |
186       430    493 88 *          hcvwS =     566 00           |
187    627 15    603 97 |                                       |
188      (61)    -34 13 |         Tsho check  K =       408 62 |
189       771    428 35 |           Tw-Tg =                  18 |
190 ----------------------------------------------------------------------
191  =              70 00
192     1 355         HEAT OUT =       1 815           DELTA H =  -0 4598
193 LL GAS       -------------------OUTSIDE COMBTION GAS -----------------
194    T  F          T. K     OLD Tg     1 760     T. F         T. K |
195       811     706 0     757.0 Tgo =         2.101    1422 2 |
196       212     373.0           Two =         1.502    1089 9 |
197       780     688 3 |         Twi =         1.099     865 7 |
198       412    228.70 | <==     Tsh =           271     406.0 |
199                     |    <==       228.7                    |
200       319    177.43 |           688.37   <=== Tw            |
201   1588.32    28.646 |                                       |
202             (310.462)|        Qwo = 0                  (29)|
203 = Qg+Qs ==  281.816 *         Qwi = Qcdwiw = Qw   (281.997)|
204 wi = Qw     281.815 *         Qgo =                 297.006 |
205  Qg = 0          (0)|         Qcdwosh =              14.980 |
206       812    706.29 *         Qwi + Qwo + Qgo =      14.980 |
207       213    373.33 *          hcvwS =     566.00           |
208    433.14    496.19 |                                       |
209      (91)    -50.71 |         Tsho check. K =       405.93 |
210         0      0.00 |           Tw-Tg =                 -18 |
211 ----------------------------------------------------------------------
212  =              70.00
213     1 355         HEAT OUT =       1 818           DELTA H =  -0.4628
214 LL GAS       -------------------OUTSIDE COMBTION GAS -----------------
215    T. F          T. K     OLD Tg     1.760     T. F         T. K |
216       747     670 0     706 3 Tgo =         2.101    1422 2 |
217       212     373 0           Two =         1.501    1088 9 |
218       773     684.6 |         Twi =         1.093     867 7 |
219       415    230.80 | <==     Tsh =           271     406 0 |
220                     |    <==       230 8                    |
```

```
  A         B          C         D                    E         F         G         H        I     J      K         L          M              N         O          P          Q       R       S      T    U
-- ---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
221 Ew          g2          -(1-TRgm1)*Emw*Aw        -1 158                                    Ewo       go2       -(1-TRgowo1)*Emwo*Awo -1 2558                           |
222                    2 00 -(TRgm1-TRgm2)*Fww*Dw*   -0.105                      |                              2 00 -(TRgowo1-TRgowo2)*Fw -0 0179                           |
223                    3 00 -(TRgm2-TRgm3)*Fww*Fww    0 010                      |                              3.00 -(TRgowo2-TRgowo3)*Fw -0 0007                           |
224                    4 00 -(TRgm2-TRgm3)*Fws*Fsw    0.004                      |                              4 00 -(TRgowo2-TRgowo3)*Fw -0 0151                           |
225                    5 00 -(TRgm2-TRgm3)*Fws*Fww    0.003                      |                              5 00 -(TRgowo2-TRgowo3)*Fw -0 0034                           |
226                    6 00 -(TRgm1-TRgm2)*Fws*Fsw   -0.030                      |                              6 00 -(TRgowo1-TRgowo2)*Fw -0.0909                           |
227 Qg => Qw                                         -1.276  (12 989) (44 345)|                      Qgo => Qwi                          -1 3838   (119.371)  (407 533)|
228                                                                              |                                                                                        |
229 Eg          g3          +Emg*Ag                   2 149                      |                      Ego       go3       +Emgo*Ago              2 0026                      |
230                    2 00 -ABg11*pw*Emg*Aw         -0 420                      |                              2 00 -ABgo11*pwo*Emgo*Awo  -0 1120                           |
231                    3 00 -(+pw*Fww+ps*Fws)*pw*T   -0.021                      |                              3 00 -(+pwo*Fwowo+pwi*Fwow -0.0316                           |
232                    4 00 -(+ABg11+pw*TRg11)*Fsw   -0.089                      |                              4 00 -(+ABgo11+pwo*TRgo11) -0 1561                           |
233 Qg => Qg                                          1.620    15.602    53 265 |                      Qgo => Qgo                           1 7029    460.472  1 572.052 |
234                                                                              |                                                                                        |
235                                                                              |                                                                                        |
236             hcvgs       +hcvgs*As*(Tg-Ts)        22575    22.575    77 072 |                                hcvgs     +hcvgowi*Awi*(Tgo-Twi   17842     17 842     60.914 |
237             hcvgw       +hcvgw*Aw*(Tg-Tw)         -379     (379)            |                                hcvgw     +hcvgowo*Awo*(Tgo-Two   13642     13.642                |
238                                                         *********            |                                                        31485 ***********                |
239 Qg =>                                                    24.677    84 247 |                      Qgo =>         .                               341.022  1 164 249 |
240                                                                              |                                                                                        |
241                                                                              |
242 ***********************************************************                |                      ***********************************************************
243                                                                              |
244                         Qs =                              (350 134)*********|                                Qwi =                Qwi =      (325.507)(1 111 281)
245                         Qw =                              325.457 *********|                                Qwo =                Qwo =              7          25
246                         Qg =                               24.677    84 247 |                                Qgo =                Qgo =        341.022  1.164.249
247                         ----------------------------------------            |                                ---------------------------------------------
248                         Qs + Qw + Qg =                        (0)       (0)|                                Qwi + Qwo + Qgo =    Qwi + Qwo     15.522      52.993
249                                                                              |
250 ***********************************************************                |                      ***********************************************************
251 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
252 *******************************************************************************************************************************************************
253 ID H2OG        500 00     750 00     1000 00   1250.00   1500.00   1750 00    2000 00
254 ----------- --------   --------   --------  --------  --------  --------   --------
255 a                0.41       0 37       0 36      0 35      0 34      0 30       0 29
256 b                0.02       0 02       0.02      0.02      0 02      0 02       0 02
257 c               -0.00      -0 00      -0.00     -0.00     -0.00     -0 00      -0.00
258
259                 Y=Emg      X=T
260         L=       3.25                 Y=Emg       X=T       X^2       X^3        X^4       XY      X^2Y          N        A =     -0.00      X=T      Y calc   Y act=Eg
261     500.00       0.47     500.00       0.47    500.00 **************************** 237.17 118583.21       1.00        B =      0.01   500.00        0.21       0.47
262     750.00       0.00     750.00       0.00    750.00 ****************************   0.00      0.00       0.00        C = *********  1000.00        0.36       0.43
263    1000.00       0.43    1000.00       0.43   1000 00 **************************** 425.73 425725.74       1.00        D =     -7.73  1250.00        0.40       0 41
264    1250.00       0.41    1250.00       0.41   1250.00 **************************** 518.34 647930.78       1 00        E = *********  1500.00        0 41       0.41
265    1500 00       0.41    1500.00       0.41   1500 00 **************************** 614.10 921153.36       1.00                       1155.60        0.39
266    1750.00       0 39    1750.00       0 39   1750 00 **************************** 690.53 **********      1 00        a =     -0.05
267    2000.00       0.36    2000.00       0 36   2000.00 **************************** 727.21 **********      1.00        b =      0.00 EMG120 = ( EMW120 @ Tw. P*L*Tw/Tg )*(Tg/Tw).45
268                ----------- --------   --------  --------  -------- --------  --------  ------- --------  --------    c =     -0.00                0.39
269                                        2.48   8750 00 ****************************3213.08 **********      6.00 PL(I =       3.25
270                                          Y          X       X#2       X#3        X#4      XY      X#2Y        N Tgl =     1155.60 IGl =        1155.60
271 *******************************************************************************************************************************************************
272 ID H2OSI       500.00     750 00     1000.00   1250.00   1500.00   1750 00    2000 00
273 ----------- --------   --------   --------  --------  --------  --------   --------
274 a                0.41       0.37       0 36      0.35      0 34      0 30       0 29
275 b                0.02       0 02       0 02      0.02      0 02      0 02       0.02
```

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
221	500.00	0.22	500.00	0.22	500.00	************			110.88	55440.56	1.00	B =	-0.00	500.00	0.21	0.22				Twi-Tw =
222	750.00	0.19	750.00	0.19	750.00	************			139.98	*********	1.00	C =	4400.00	1000.00	0.18	0.17				Qg = 0
223	1000.00	0.17	1000.00	0.17	1000.00	************			171.26	*********	1.00	D =	0.22	1500.00	0.14	0.15				Qs =
224	1500.00	0.15	1500.00	0.15	1500.00	************			217.75	*********	1.00	E =	*********	2000.00	0.11	0.12				Qw' = Qcd
225	2000.00	0.12	2000.00	0.12	2000.00	************			231.70	*********	1.00			2500.00	0.09	0.09				Qcdwiw = Q
226	2500.00	0.09	2500.00	0.09	2500.00	************			226.83	*********	1.00	a =	0.26	3000.00	0.07	0.07				Qs + Qw' +
227	3000.00	0.07	3000.00	0.07	3000.00	************			215.41	*********	1.00	b =	-0.00	3500.00	0.06	0.06				NEW Tg =
228	3500.00	0.06	3500.00	0.06	3500.00	************			201.46	*********	1.00	c =	0.00	4000.00	0.05	0.05				NEW Ts =
229	4000.00	0.05	4000.00	0.05	4000.00	************			182.15	*********	1.00			1540.45	0.14					OLD Ts =
230		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------									DEL Tg, K
231		500.00		1.11	18750.00	************					9.00		ABGS2 = (ABCO2+ABH2O)(1-CSO1)							DEL Ts, K
232				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.30						----------
233													ABCO2 = (EMCO2 @ Ts, P*L*Ts/Tg)*(Tg/Ts).65							PAUX LB/HR
234														0.15						HEAT IN =
235	CO2S2	500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	*******				ABH2O = (EWH2O @ Ts, P*L*Ts/Tg)*(Tg/Ts).45							INSIDE SHE
236	--------	--------	--------	--------	--------	--------	--------	--------	--------					0.18						
237	a	0.08	0.07	0.08	0.07	0.06	0.04	0.04	0.03											Tg =
238	b	0.11	0.10	0.10	0.12	0.11	0.10	0.08	0.07			Tg =		2660.00 PL2*Ts/Tg		0.35				Ts =
239	c	-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02			,Ts =		1540.45 Cso2 =		0.06				Tw =
240																				Two-Twi =
241		Y=Emg	X=T																	
242	L=	0.35		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=I	Y Calc	Y act=Eg		Twi-Tw =
243	500.00	0.12	500.00	0.12	500.00	************			59.40	29690.45	1.00	B =	-0.00	B =	-0.00	500.00	0.12	0.12		Qg = 0
244	1000.00	0.10	1000.00	0.10	1000.00	************			98.12	98117.26	1.00	C =	2500.00	C =	6500.00	1000.00	0.10	0.10		Qs =
245	1500.00	0.11	1500.00	0.11	1500.00	************			161.22	*********	1.00	D =	0.11	D =	0.17	1500.00	0.10	0.11		Qw' = Qcd
246	2000.00	0.11	2000.00	0.11	2000.00	************			216.72	*********	1.00	E =	*********	E =	*********	2000.00	0.11	0.11		Qcdwiw = Q
247		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------					2500.00	0.09	0.09		Qs + Qw' +
248		500.00		0.43	5000.00	************			535.46	*********	4.00	a =	0.14	a =	0.20	3000.00	0.08	0.08		NEW Tg =
249				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0.00	3500.00	0.06	0.06		NEW Ts =
250												c =	0.00	c =	0.00	4000.00	0.05	0.05		OLD Ts =
251	L=	0.35		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1540.45	0.10			DEL Tg, K
252	2500.00	0.09	2500.00	0.09	2500.00	************			231.96	*********	1.00									DEL Ts, K
253	3000.00	0.08	3000.00	0.08	3000.00	************			228.34	*********	1.00									----------
254	3500.00	0.06	3500.00	0.06	3500.00	************			213.83	*********	1.00									PAUX LB/HR
255	4000.00	0.05	4000.00	0.05	4000.00	************			192.24	*********	1.00									HEAT IN =
256		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------									INSIDE SHE
257		500.00		0.28	13000.00	************			866.37	*********	4.00									
258				Y	X	X#2	X#3	X#4	XY	X#2Y	N									Tg =
259	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************				Ts =
260																				Tw =
261	H2O2W	500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	*******	750.00										Two-Twi =
262	a	0.13	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.09										
263	b	0.30	0.29	0.27	0.22	0.20	0.16	0.15	0.12	0.29										Twi-Tw =
264	c	-0.08	-0.08	-0.07	-0.05	-0.05	-0.04	-0.04	-0.03	-0.08										Qg = 0
265																				Qs =
266		Y=Emg	X=T																	Qw' = Qcd
267	L=	0.46		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y Calc	Y act=Eg				Qcdwiw = Q
268	500.00	0.25	500.00	0.25	500.00	************			123.05	61525.21	1.00	B =	-0.00	500.00	0.24	0.25				Qs + Qw' +
269	750.00	0.21	750.00	0.21	750.00	************			157.90	*********	1.00	C =	4400.00	1000.00	0.20	0.19				NEW Tg =
270	1000.00	0.19	1000.00	0.19	1000.00	************			194.74	*********	1.00	D =	0.25	1500.00	0.16	0.17				NEW Ts =
271	1500.00	0.17	1500.00	0.17	1500.00	************			250.71	*********	1.00	E =	*********	2000.00	0.13	0.13				OLD Ts =
272	2000.00	0.13	2000.00	0.13	2000.00	************			269.25	*********	1.00			2500.00	0.11	0.11				DEL Tg, K
273	2500.00	0.11	2500.00	0.11	2500.00	************			267.87	*********	1.00	a =	0.28	3000.00	0.09	0.09				DEL Ts, K
274	3000.00	0.09	3000.00	0.09	3000.00	************			256.93	*********	1.00	b =	-0.00	3500.00	0.07	0.07				----------
275	3500.00	0.07	3500.00	0.07	3500.00	************			244.30	*********	1.00	c =	0.00	4000.00	0.06	0.06				

```
            AQ          AR          AS          AT          AU          AV        AW        AX        AY        AZ
-- ---------------------------------------------------------------------------------------------------------------
221        321     178.09 |              684.62    <=== Tw             |
222    1588.32     20.726 |                                            |
223              (303.595)|          Qwo = 0                       (23)|
224 = Qg+Qs ==   282.869 *          Qwl = QCdwlw = Qw     (282.899)|
225 wl = Qw      282.868 *          Qgo =                   297.881 |
226  Qg = 0           (0)|          Qcdwosh =                14.959 |
227        746     669.41 *          Qwl + Qwo + Qgo =        14.959 |
228        213     373.33 *           hcvwS =      566.00           |
229     428.26     493.48 |                                            |
230       (66)     -36.88 |          Tsho check. K =         405.79 |
231          0       0.00 |            Tw-Tg =                    15 |
232 -------------------------------------------------------------------------
233  =               70.00
234      1.355          HEAT OUT =        1.820             DELTA H =  -0.4650
235 LL GAS          --------------------OUTSIDE COMBTION GAS -----------------
236     T. F          T. K     OLD Tg       1.760      T. F         T. K |
237        698       643.0     669.4 Tgo =             2.101       1422.2 |
238        212       373.0           Two =             1.499       1088.1 |
239        768       682.0 |         Twl =             1.089        860.5 |
240        418      232.30 | <==     Tsh =               271        406.0 |
241                        |    <==       232.3                           |
242        321     178.48 |              682.03    <=== Tw             |
243    1588.32     15.239 |                                            |
244              (298.730)|          Qwo = 0                       (59)|
245 = Qg+Qs ==   283.491 *          Qwl = QCdwlw = Qw     (283.524)|
246 wl = Qw      283.491 *          Qgo =                   298.526 |
247  Qg = 0           (0)|          Qcdwosh =                14.942 |
248        697     642.18 *          Qwl + Qwo + Qgo =        14.942 |
249        213     373.33 *           hcvwS =      566.00           |
250     424.81     491.56 |                                            |
251       (49)     -27.23 |          Tsho check. K =         405.69 |
252          0       0.00 |            Tw-Tg =                    39 |
253 -------------------------------------------------------------------------
254  =               70.00
255      1.355          HEAT OUT =        1.868             DELTA H =  -0.5131
256 LL GAS          --------------------OUTSIDE COMBTION GAS -----------------
257     T. F          T. K     OLD Tg       1.760      T. F         T. K |
258        621       600.0     642.2 Tgo =             2.101       1422.2 |
259         61       289.0           Two =             1.471       1072.3 |
260        656       619.6 |         Twl =               993        807.2 |
261        487      270.50 | <==     Tsh =               264        402.0 |
262                        |    <==       270.5                           |
263        338     187.56 |              619.61    <=== Tw             |
264    1588.32     20.054 |                                            |
265              (317.965)|          Qwo = 0                       (37)|
266 = Qg+Qs ==   297.911 *          Qwl = QCdwlw = Qw     (297.909)|
267 wl = Qw      297.910 *          Qgo =                   312.628 |
268  Qg = 0           (0)|          Qcdwosh =                14.682 |
269        632     606.13 *          Qwl + Qwo + Qgo =        14.682 |
270        (6)     251.84 *           hcvwS =      566.00           |
271     219.78     377.66 |                                            |
272       (65)     -36.05 |          Tsho check. K =         404.23 |
273        219     121.49 |            Tw-Tg =                    20 |
274 -------------------------------------------------------------------------
275
```

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
276 C		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00												
277																				
278		Y=Emg	X=T																	
279	Ts	1.46		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	-0.00	X=T	Y calc	Y act=Eg				
280	500.00	0.44	500.00	0.44	500.00	***************************			220.38	110188.73	1.00	B =	0.01	500.00	0.19	0.44				
281	750.00	0.00	750.00	0.00	750.00	***************************			0.00	0.00	0.00	C =	*********	1000.00	0.34	0.40				
282	1000.00	0.40	1000.00	0.40	1000.00	***************************			396.54	396535.38	1.00	D =	-7.28	1250.00	0.37	0.38				
283	1250.00	0.38	1250.00	0.38	1250.00	***************************			479.20	599005.46	1.00	E =	*********	1500.00	0.38	0.38				
284	1500.00	0.38	1500.00	0.38	1500.00	***************************			569.01	853519.32	1.00			520.20	0.20					
285	1750.00	0.36	1750.00	0.36	1750.00	***************************			637.77	*********	1.00	a =	-0.05							
286	2000.00	0.33	2000.00	0.33	2000.00	***************************			661.01	*********	1.00	b =	0.00	ABH2Os) = (EwH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw) 45						
287		-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------	c =	-0.00		0.29					
288				2.29	8750.00	***************************			2963.91	*********	6.00 PL(1) =		3.25							
289				Y	X	X#2	X#3	X#4	XY	X#2Y	N Tg) =		1155.60	TSi =	520.20					
290	************																			
291 ID H2O1W		500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00												
292	-----------	--------	--------	--------	--------	--------	--------	--------												
293 a		0.41	0.37	0.36	0.35	0.34	0.30	0.29												
294 b		0.02	0.02	0.02	0.02	0.02	0.02	0.02												
295 c		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00												
296																				
297		Y=Emg	X=T																	
298	Ts	3.29		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	-0.00	X=T	Y calc	Y act=Eg				
299	500.00	0.48	500.00	0.48	500.00	***************************			237.58	118790.00	1.00	B =	0.01	500.00	0.21	0.48				
300	750.00	0.00	750.00	0.00	750.00	***************************			0.00	0.00	0.00	C =	*********	1000.00	0.36	0.43				
301	1000.00	0.43	1000.00	0.43	1000.00	***************************			426.45	426445.03	1.00	D =	-7.74	1250.00	0.40	0.42				
302	1250.00	0.42	1250.00	0.42	1250.00	***************************			519.31	649135.17	1.00	E =	*********	1500.00	0.41	0.41				
303	1500.00	0.41	1500.00	0.41	1500.00	***************************			615.21	922821.22	1.00			1171.62	0.39					
304	1750.00	0.40	1750.00	0.40	1750.00	***************************			691.83	*********	1.00	a =	-0.05							
305	2000.00	0.36	2000.00	0.36	2000.00	***************************			728.84	*********	1.00	b =	0.00	ABH2O = (EwH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw) 45						
306		-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------	c =	-0.00		0.39					
307				2.49	8750.00	***************************			3219.21	*********	6.00 PL(1) =		3.25							
308				Y	X	X#2	X#3	X#4	XY	X#2Y	N Tg) =		1155.60	TWi =	1171.62					
309	************																			
310 ID H2O2S		500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00												
311	-----------	--------	--------	--------	--------	--------	--------	--------												
312 a		0.41	0.37	0.36	0.35	0.34	0.30	0.29												
313 b		0.02	0.02	0.02	0.02	0.02	0.02	0.02												
314 c		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00												
315																				
316		Y=Emg	X=T																	
317	Ts	1.27		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	-0.00	X=T	Y calc	Y act=Eg				
318	500.00	0.44	500.00	0.44	500.00	***************************			218.53	109265.25	1.00	B =	0.01	500.00	0.19	0.44				
319	750.00	0.00	750.00	0.00	750.00	***************************			0.00	0.00	0.00	C =	*********	1000.00	0.33	0.39				
320	1000.00	0.39	1000.00	0.39	1000.00	***************************			393.33	393325.04	1.00	D =	-7.23	1250.00	0.37	0.38				
321	1250.00	0.38	1250.00	0.38	1250.00	***************************			474.90	593619.16	1.00	E =	*********	1500.00	0.38	0.38				
322	1500.00	0.38	1500.00	0.38	1500.00	***************************			564.06	846086.71	1.00			520.20	0.20					
323	1750.00	0.36	1750.00	0.36	1750.00	***************************			631.97	*********	1.00	a =	-0.05							
324	2000.00	0.33	2000.00	0.33	2000.00	***************************			653.73	*********	1.00	b =	0.00	ABH2O = (EwH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw) 45						
325		-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------	c =	-0.00		0.41					
326				2.27	8750.00	***************************			2936.50	*********	6.00 PL(2) =		6.50							
327				Y	X	X#2	X#3	X#4	XY	X#2Y	N Tg) =		2660.00	TSi =	520.20					
328	************																			
329 ID H2O2W		500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00												
330	-----------	--------	--------	--------	--------	--------	--------	--------												

		V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
276		4000 00	0 06	4000 00	0 06	4000.00	*********	*********	*********	222 06	*********	1 00			1999 09	0 13					
277			---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
278			500 00		1.27	18750.00	*********	*********	*********	*********	*********	9 00	ABgw2 = (ABCO2+ABH2O)(1-CSO1)								
279					Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.28						
280													ABCO2 = (EMCO2 @ Tw. P*L*Tw/Tg)*(Tg/Tw).65								
281															0 14						
282	CO2W2		500 00	1000 00	1500 00	2000 00	2500 00	3000 00	3500 00	*******			ABH2O = (EMH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw) 45								
283	---------		--------	--------	--------	--------	--------	--------	--------	--------					0 15						
284	a		0 08	0 07	0 08	0.07	0.06	0 04	0 04	0.03											
285	b		0 11	0 10	0 10	0 12	0.11	0 10	0 08	0.07			Tg =		2660 00	PL1*Tw/Tg	0 46				
286	c		-0 03	-0 03	-0 03	-0.03	-0.03	-0 02	-0 02	-0 02			Tw =		1999 09	CSO1 =	0 06				
287																					
288			Y=Emg	X=T																	
289		L=	0 46		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0 00	X=T	Y calc	Y act=Eg		
290		500.00	0 13	500 00	0 13	500.00	*********	*********	*********	63.66	31831 16	1 00	B =	-0 00	B =	-0.00	500.00	0.13	0.13		
291		1000.00	0 11	1000 00	0 11	1000.00	*********	*********	*********	106.35	*********	1 00	C =	2500.00	C =	6500.00	1000.00	0 11	0.11		
292		1500.00	0 12	1500 00	0 12	1500.00	*********	*********	*********	173.04	*********	1 00	D =	0 12	D =	0.18	1500.00	0 11	0.12		
293		2000.00	0 12	2000 00	0 12	2000.00	*********	*********	*********	236.09	*********	1.00	E =	*********	E =	*********	2000.00	0 12	0.12		
294			---------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500.00	0 10	0.10		
295			500 00		0 47	5000 00	*********	*********	*********	579 14	*********	4 00	a =	0 15	a =	0 22	3000.00	0.08	0.08		
296					Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0 00	3500 00	0 07	0 07		
297													c =	0 00	c =	0 00	4000 00	0 05	0.05		
298		L=	0 46		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1999 09	0 12			
299		2500 00	0 10	2500 00	0 10	2500 00	*********	*********	*********	255 69	*********	1 00									
300		3000 00	0 08	3000 00	0 08	3000.00	*********	*********	*********	253 03	*********	1 00									
301		3500 00	0 07	3500 00	0 07	3500 00	*********	*********	*********	237 67	*********	1 00									
302		4000 00	0 05	4000 00	0 05	4000.00	*********	*********	*********	214 55	*********	1 00									
303			---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
304			500 00		0 31	13000.00	*********	*********	*********	960 93	*********	4.00									
305					Y	X	X#2	X#3	X#4	XY	X#2Y	N									
306	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********			
307																					
308	H2O3S		500 00	1000 00	1500.00	2000.00	2500.00	3000 00	3500.00	*******	750 00										
309	a		0.13	0 08	0.06	0.04	0.03	0 02	0.01	0.01	0.09										
310	b		0.30	0 29	0.27	0 22	0 20	0 16	0 15	0.12	0.29										
311	c		-0 08	-0 08	-0.07	-0.05	-0.05	-0.04	-0.04	-0.03	-0.08										
312																					
313			Y=Emg	X=T																	
314		L=	0 53		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg				
315		500.00	0.26	500 00	0 26	500.00	*********	*********	*********	130.82	65408.36	1 00	B =	-0.00	500.00	0.25	0.26				
316		750.00	0 23	750 00	0 23	750.00	*********	*********	*********	169.31	*********	1.00	C =	4400 00	1000 00	0 21	0.21				
317		1000.00	0 21	1000 00	0 21	1000.00	*********	*********	*********	209 72	*********	1.00	D =	0 27	1500.00	0.18	0.18				
318		1500.00	0 18	1500.00	0.18	1500.00	*********	*********	*********	271.81	*********	1 00	E =	*********	2000.00	0.15	0.15				
319		2000.00	0 15	2000 00	0.15	2000.00	*********	*********	*********	293.47	*********	1.00			2500.00	0.12	0 12				
320		2500.00	0.12	2500.00	0.12	2500.00	*********	*********	*********	294.26	*********	1.00	a =	0.30	3000.00	0.10	0.09				
321		3000.00	0.09	3000 00	0.09	3000.00	*********	*********	*********	283.79	*********	1.00	b =	-0.00	3500 00	0 08	0 08				
322		3500.00	0.08	3500.00	0 08	3500.00	*********	*********	*********	271.85	*********	1 00	c =	0.00	4000.00	0.06	0.06				
323		4000.00	0.06	4000 00	0.06	4000.00	*********	*********	*********	247.90	*********	1 00			1540.45	0.17					
324			---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
325			500 00		1 38	18750.00	*********	*********	*********	*********	*********	9 00	ABgS3 = (ABCO2+ABH2O)(1-CSO1)								
326					Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.36						
327													ABCO2 = (EMCO2 @ Ts. P*L*Ts/Tg)*(Tg/Ts).65								
328															0.16						
329	CO2S3		500 00	1000 00	1500 00	2000.00	2500 00	3000 00	3500.00	*******			ABH2O = (EMH2O @ Ts. P*L*Ts/Tg)*(Tg/Ts) 45								
330	---------		--------	--------	--------	--------	--------	--------	--------	--------					0.22						

```
A        B          C        D        E        F        G        H        I        J        K          L        M      N          O          P          Q         R   S   T   U
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
331 a               0.41     0.37     0.36     0.35     0.34     0.30     0.29
332 b               0.02     0.02     0.02     0.02     0.02     0.02     0.02
333 c              -0.00    -0.00    -0.00    -0.00    -0.00    -0.00    -0.00
334
335                 Y=Emg    X=T
336      L=         2.86              Y=Emg    X=T      X^2      X^3      X^4      XY       X^2Y       N        A =   -0.00      X=T        Y calc     Y act=Eg
337      500.00     0.47     500.00   0.47     500.00 ***************************** 233.59 116797.01   1.00     B =    0.01      500.00     0.20       0.47
338      750.00     0.00     750.00   0.00     750.00 *****************************   0.00      0.00   0.00     C = *********  1000.00    0.36       0.42
339     1000.00     0.42    1000.00   0.42    1000.00 ***************************** 419.51 419513.25   1.00     D =   -7.63    1250.00     0.39       0.41
340     1250.00     0.41    1250.00   0.41    1250.00 ***************************** 510.02 637526.05   1.00     E = *********  1500.00    0.40       0.40
341     15__.00     0.40    1500.00   0.40    1500.00 ***************************** 604.50 906750.84   1.00                    1171.62    0.38
342     1750.00     0.39    1750.00   0.39    1750.00 ***************************** 679.30 *********   1.00     a =   -0.05
343     2000.00     0.36    2000.00   0.36    2000.00 ***************************** 713.13 *********   1.00     b =    0.00 ABH2O = ( EMH2O @ Tw. P*L*Tw/Tg )*(Tg/Tw).45
344             ----------- --------  -------- -------- -------- -------- -------- ------- --------  --------  c =   -0.00                 0.56
345                                   2.44    8750.00 *****************************3160.05 *********   6.00 PL(2 =        6.50
346                                   Y        X        X#2      X#3      X#4      XY       X#2Y       N Tgi =      2660.00 Twi =          1171.62
347 ************************************************************************************************************************************************************
348 ID H2O3S        500.00   750.00  1000.00  1250.00  1500.00  1750.00  2000.00
349 ----------- -------- -------- -------- -------- -------- -------- --------
350 a               0.41     0.37     0.36     0.35     0.34     0.30     0.29
351 b               0.02     0.02     0.02     0.02     0.02     0.02     0.02
352 c              -0.00    -0.00    -0.00    -0.00    -0.00    -0.00    -0.00
353
354                 Y=Emg    X=T
355      L=         1.91              Y=Emg    X=T      X^2      X^3      X^4      XY       X^2Y       N        A =   -0.00      X=T        Y calc     Y act=Eg
356      500.00     0.45     500.00   0.45     500.00 ***************************** 224.62 112308.25   1.00     B =    0.01      500.00     0.20       0.45
357      750.00     0.00     750.00   0.00     750.00 *****************************   0.00      0.00   0.00     C = *********  1000.00    0.34       0.40
358     1000.00     0.40    1000.00   0.40    1000.00 ***************************** 403.90 403904.23   1.00     D =   -7.39    1250.00     0.38       0.39
359     1250.00     0.39    1250.00   0.39    1250.00 ***************************** 489.09 611364.90   1.00     E = *********  1500.00    0.39       0.39
360     1500.00     0.39    1500.00   0.39    1500.00 ***************************** 580.39 870583.92   1.00                     520.20    0.20
361     1750.00     0.37    1750.00   0.37    1750.00 ***************************** 651.09 *********   1.00     a =   -0.05
362     2000.00     0.34    2000.00   0.34    2000.00 ***************************** 677.73 *********   1.00     b =    0.00 ABH2O = ( EMH2O @ Ts. P*L*Tm/Tg )*(Tg/Tm).45
363             ----------- --------  -------- -------- -------- -------- -------- ------- --------  --------  c =   -0.00                 0.42
364                                   2.34    8750.00 *****************************3026.82 *********   6.00 PL(3 =        9.75
365                                   Y        X        X#2      X#3      X#4      XY       X#2Y       N Tgi =      2660.00 TSi =           520.20
366 ************************************************************************************************************************************************************
367 ID H2O3W        500.00   750.00  1000.00  1250.00  1500.00  1750.00  2000.00
368 ----------- -------- -------- -------- -------- -------- -------- --------
369 a               0.41     0.37     0.36     0.35     0.34     0.30     0.29
370 b               0.02     0.02     0.02     0.02     0.02     0.02     0.02
371 c              -0.00    -0.00    -0.00    -0.00    -0.00    -0.00    -0.00
372
373                 Y=Emg    X=T
374      L=         9.88              Y=Emg    X=T      X^2      X^3      X^4      XY       X^2Y       N        A =   -0.00      X=T        Y calc     Y act=Eg
375      500.00     0.59     500.00   0.59     500.00 ***************************** 292.94 146468.91   1.00     B =    0.01      500.00     0.25       0.59
376      750.00     0.00     750.00   0.00     750.00 *****************************   0.00      0.00   0.00     C = *********  1000.00    0.45       0.52
377     1000.00     0.52    1000.00   0.52    1000.00 ***************************** 522.83 522826.95   1.00     D =   -9.22    1250.00     0.50       0.52
378     1250.00     0.52    1250.00   0.52    1250.00 ***************************** 647.89 809866.65   1.00     E = *********  1500.00    0.52       0.51
379     1500.00     0.51    1500.00   0.51    1500.00 ***************************** 764.65 *********   1.00                    1171.62    0.48
380     1750.00     0.49    1750.00   0.49    1750.00 ***************************** 866.14 *********   1.00     a =   -0.07
381     2000.00     0.47    2000.00   0.47    2000.00 ***************************** 946.68 *********   1.00     b =    0.00 ABH2O = ( EMH2O @ Tw. P*L*Tw/Tg )*(Tg/Tw).45
382             ----------- --------  -------- -------- -------- -------- -------- ------- --------  --------  c =   -0.00                 0.48
383                                   3.11    8750.00 *****************************4041.13 *********   6.00 PL(3 =        9.75
384                                   Y        X        X#2      X#3      X#4      XY       X#2Y       N Tgi =      1155.60 Twi =          1171.62
385 ************************************************************************************************************************************************************
```

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
331	a	0 08	0 07	0 08	0 07	0 06	0 04	0 04	0 03											
332	b	0 11	0 10	0 10	0 12	0 11	0 10	0 08	0 07				Tg =	2660 00	plo3 =	0 91				
333	c	-0 03	-0 03	-0 03	-0 03	-0 03	-0 02	-0 02	-0 02				Ts =	1540 45	Cso3 =	0 08				
334																				
335		Y=Emg	X=I																	
336	L=	0 53		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	A =	0 00	X=I	Y calc	Y act=Eg		
337	500 00	0 13	500 00	0 13	500.00	*********	*********	*********	66 35	33173 40	1 00	B =	-0 00	B =	-0 00	500 00	0 13	0 13		
338	1000 00	0 11	1000 00	0.11	1000.00	*********	*********	*********	111 59	*********	1 00	C =	2500 00	C =	6500 00	1000 00	0 12	0 11		
339	1500 00	0 12	1500 00	0.12	1500.00	*********	*********	*********	180 59	*********	1 00	D =	0.13	D =	0 19	1500 00	0 12	0 12		
340	2000 00	0 12	2000 00	0 12	2000.00	*********	*********	*********	248 43	*********	1 00	E =	*********	E =	*********	2000 00	0 13	0 12		
341	---------	--------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500 00	0 11	0 11		
342		500 00		0 49	5000 00	*********	*********	*********	606 96	*********	4 00	a =	0 16	a =	0 23	3000 00	0 09	0 09		
343				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0 00	3500 00	0 07	0 07		
344												c =	0 00	c =	0 00	4000 00	0 06	0 06		
345	L=	0 53		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N					1540 45	0 12			
346	2500 00	0 11	2500 00	0 11	2500 00	*********	*********	*********	270 88	*********	1 00									
347	3000 00	0 09	3000 00	0 09	3000 00	*********	*********	*********	268.91	*********	1 00									
348	3500 00	0 07	3500 00	0 07	3500 00	*********	*********	*********	253 00	*********	1 00									
349	4000 00	0 06	4000 00	0 06	4000 00	*********	*********	*********	228.91	*********	1 00									
350	---------	--------	--------	--------	--------	--------	--------	--------	------	--------	--------									
351		500 00		0 33	13000 00	*********	*********	*********	*********	*********	4 00									
352				Y	X	X#2	X#3	X#4	XY	X#2Y	N									
353	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********				
354																				
355	H2O3W	500 00	1000 00	1500.00	2000 00	2500 00	3000 00	3500 00	*******	750 00										
356	a	0.13	0 08	0 06	0 04	0 03	0 02	0 01	0 01	0 09										
357	b	0 30	0 29	0.27	0 22	0 20	0 16	0 15	0 12	0 29										
358	c	-0 08	-0 08	-0 07	-0 05	-0 05	-0 04	-0 04	-0 03	-0 08										
359																				
360		Y=Emg	X=I																	
361	L=	0 68		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=I	V calc	Y act=Eg				
362	500.00	0 29	500 00	0 29	500.00	*********	*********	*********	146.53	73264 09	1 00	B =	-0 00	500.00	0.29	0.29				
363	750 00	0.26	750.00	0.26	750 00	*********	*********	*********	192.29	*********	1.00	C =	4400.00	1000.00	0.24	0.24				
364	1000 00	0.24	1000 00	0 24	1000.00	*********	*********	*********	240.00	*********	1 00	D =	0 30	1500.00	0.20	0.21				
365	1500.00	0.21	1500 00	0 21	1500.00	*********	*********	*********	314.66	*********	1 00	E =	*********	2000.00	0.17	0.17				
366	2000 00	0 17	2000 00	0 17	2000 00	*********	*********	*********	343 21	*********	1 00			2500.00	0.14	0.14				
367	2500 00	0 14	2500 00	0 14	2500 00	*********	*********	*********	348 24	*********	1 00	a =	0 33	3000.00	0 11	0 11				
368	3000 00	0.11	3000.00	0 11	3000.00	*********	*********	*********	339 18	*********	1 00	b =	-0.00	3500 00	0.09	0.09				
369	3500.00	0.09	3500 00	0 09	3500.00	*********	*********	*********	328 20	*********	1 00	c =	0 00	4000.00	0 08	0 08				
370	4000.00	0.08	4000 00	0 08	4000 00	*********	*********	*********	301.30	*********	1 00			1999 09	0 17					
371	---------	--------	--------	--------	--------	--------	--------	--------	------	--------	--------									
372		500 00		1 59	18750 00	*********	*********	*********	*********	*********	9 00		ABgw3 = (ABCO2+ABH2O)(1-CSO3)							
373				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.33						
374													ABCO2 = (EMCO2 @ Tw, P*L*Tw/Tg)*(Tg/Tw).65							
375														0.17						
376	CO2W3	500.00	1000 00	1500.00	2000.00	2500.00	3000.00	3500.00	*******				ABH2O = (EMH2O @ Tw, P*L*Tw/Tg)*(Tg/Tw) 45							
377	---------	--------	--------	--------	--------	--------	--------	--------	--------					0.19						
378	a	0.08	0.07	0.08	0 07	0 06	0 04	0 04	0 03											
379	b	0 11	0 10	0 10	0 12	0 11	0 10	0 08	0 07				Tg =	2660.00	PL1*Tw/Tg	0 68				
380	c	-0 03	-0 03	-0 03	-0 03	-0.03	-0.02	-0 02	-0 02				Tw =	1999 09	Cso3 =	0 08				
381																				
382		Y=Emg	X=I																	
383	L=	0 68		Y=Emg	X=I	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=I	Y calc	Y act=Eg		
384	500 00	0 14	500 00	0.14	500.00	*********	*********	*********	71.66	35831 32	1 00	B =	-0.00	B =	-0.00	500.00	0 14	0 14		
385	1000 00	0.12	1000 00	0 12	1000 00	*********	*********	*********	122 18	*********	1 00	C =	2500.00	C =	6500.00	1000 00	0 13	0 12		

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
386	ID H2092		500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00												
387	-----------		--------	--------	--------	--------	--------	--------	--------												
388	a		0.41	0.37	0.36	0.35	0.34	0.30	0.29												
389	b		0.02	0.02	0.02	0.02	0.02	0.02	0.02												
390	c		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00												
391																					
392			Y=Emg	X=T																	
393		t =	6.50		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	-0.00	X=T	Y calc	Y act=Eg				
394		500.00	0.53	500.00	0.53	500.00	******************************			265.78	132888.42	1.00	B =	0.01	500.00	0.23	0.53				
395		750.00	0.00	750.00	0.00	750.00	******************************			0.00	0.00	0.00	C =	*********	1000.00	0.40	0.48				
396		1000.00	0.48	1000.00	0.48	1000.00	******************************			475.51	475508.75	1.00	D =	-8.49	1250.00	0.45	0.47				
397		1250.00	0.47	1250.00	0.47	1250.00	******************************			584.91	731132.74	1.00	E =	*********	1500.00	0.46	0.46				
398		1500.00	0.46	1500.00	0.46	1500.00	******************************			691.17	*********	1.00			1155.60	0.44					
399		1750.00	0.45	1750.00	0.45	1750.00	******************************			780.54	*********	1.00	a =	-0.06							
400		2000.00	0.42	2000.00	0.42	2000.00	******************************			839.89	*********	1.00	b =	0.00	ABH2O = (EwH2O @ Tw. P*L*Tw/Tg)*(Tg/Tw) 45						
401			-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------	C =	-0.00		0.44					
402					2.80	8750.00	******************************			3637.79	*********	6.00	PL2 =	6.50							
403					Y	X	X#2	X#3	X#4	XY	X#2Y	N	Tgl =	1155.60	Tgl =	1155.60					
404	**																				
405	ID H20g3		500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00												
406	-----------		--------	--------	--------	--------	--------	--------	--------												
407	a		0.41	0.37	0.36	0.35	0.34	0.30	0.29												
408	b		0.02	0.02	0.02	0.02	0.02	0.02	0.02												
409	c		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00												
410																					
411			Y=Emg	X=T																	
412		t =	9.75		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	-0.00	X=T	Y calc	Y act=Eg				
413		500.00	0.58	500.00	0.58	500.00	******************************			291.90	145952.47	1.00	B =	0.01	500.00	0.25	0.58				
414		750.00	0.00	750.00	0.00	750.00	******************************			0.00	0.00	0.00	C =	*********	1000.00	0.44	0.52				
415		1000.00	0.52	1000.00	0.52	1000.00	******************************			521.03	521026.32	1.00	D =	-9.20	1250.00	0.49	0.52				
416		1250.00	0.52	1250.00	0.52	1250.00	******************************			645.50	806878.00	1.00	E =	*********	1500.00	0.51	0.51				
417		1500.00	0.51	1500.00	0.51	1500.00	******************************			761.85	*********	1.00			1155.60	0.48					
418		1750.00	0.49	1750.00	0.49	1750.00	******************************			862.88	*********	1.00	a =	-0.07							
419		2000.00	0.47	2000.00	0.47	2000.00	******************************			942.62	*********	1.00	b =	0.00	ABH2O = (EwH2O @ Tw P*L*Tw/Tg)*(Tg/Tw).45						
420			-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------	C =	-0.00		0.48					
421					3.09	8750.00	******************************			4025.79	*********	6.00	PL3 =	9.75							
422					Y	X	X#2	X#3	X#4	XY	X#2Y	N	Tgl =	1155.60	Tg =	1155.60					
423	**																				
424	H20g3		500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	4000.00	750.00										
425	a		0.13	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.09										
426	b		0.30	0.29	0.27	0.22	0.20	0.16	0.15	0.12	0.29										
427	c		-0.08	-0.08	-0.07	-0.05	-0.05	-0.04	-0.04	-0.03	-0.08										
428																					
429			Y=Emg	X=T																	
430		t =	0.91		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	X=T	Y calc	Y act=Eg				
431		500.00	0.33	500.00	0.33	500.00	******************************			165.69	82846.06	1.00	B =	-0.00	500.00	0.33	0.33				
432		750.00	0.29	750.00	0.29	750.00	******************************			220.05	165039.51	1.00	C =	4400.00	1000.00	0.28	0.28				
433		1000.00	0.28	1000.00	0.28	1000.00	******************************			276.91	276906.83	1.00	D =	0.35	1500.00	0.24	0.24				
434		1500.00	0.24	1500.00	0.24	1500.00	******************************			367.40	551102.02	1.00	E =	*********	2000.00	0.20	0.20				
435		2000.00	0.20	2000.00	0.20	2000.00	******************************			405.91	811815.95	1.00			2500.00	0.17	0.17				
436		2500.00	0.17	2500.00	0.17	2500.00	******************************			415.64	*********	1.00	a =	0.37	3000.00	0.14	0.14				
437		3000.00	0.14	3000.00	0.14	3000.00	******************************			409.58	*********	1.00	b =	-0.00	3500.00	0.11	0.11				
438		3500.00	0.11	3500.00	0.11	3500.00	******************************			398.57	*********	1.00	c =	0.00	4000.00	0.09	0.09				
439		4000.00	0.09	4000.00	0.09	4000.00	******************************			369.41	*********	1.00			2660.00	0.16					
440			-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------									

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
386	1500 00	0 13	1500 00	0 13	1500 00	********	********	********	195 91	*********	1 00	D =	0 14	D =	0 21	1500 00	0 13	0 13		
387	2000.00	0 4	2000 00	0 14	2000 00	********	********	********	273 31	*********	1 00	E =	*********	E =	*********	2000 00	0 14	0 14		
388		---------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500 00	0 12	0 12		
389				0 53	5000.00	********	********	********	663 06	*********	4 00	a =	0 17	a =	0 25	3000.00	0 10	0 10		
390				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0 00	b =	-0 00	3500 00	0 08	0 08		
391												c =	0 00	c =	0 00	4000 00	0 06	0 06		
392	L=	0 68		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					1999 09	0 14			
393	2500 00	0 12	2500 00	0 12	2500 00	********	********	********	301 73	*********	1 00									
394	3000.00	0 10	3000 00	0 10	3000 00	********	********	********	301 45	*********	1 00									
395	3500 00	0 08	3500 00	0 08	3500.00	********	********	********	284 40	*********	1 00									
396	4000 00	0 06	4000 00	0 06	4000 00	********	********	********	258 36	*********	1 00									
397		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
398				0 37	13000 00	********	********	********	********	*********	4 00									
399				Y	X	X#2	X#3	X#4	XY	X#2Y	N									
400	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********	********				
401																				
402	H2Og2	500 00	1000 00	1500 00	2000 00	2500 00	3000 00	3500 00	*******	750.00										
403	a	0 13	0 08	0 06	0 04	0 03	0.02	0 01	0 01	0 09										
404	b	0 30	0 29	0 27	0 22	0 20	0 16	0.15	0 12	0 29										
405	c	-0 08	-0 08	-0 07	-0 05	-0 05	-0 04	-0.04	-0 03	-0 08										
406																				
407		Y=Emg	X=T																	
408	L=	0 61		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0 00	X=T	Y calc	Y act=Eg				
409	500.00	0 28	500 00	0 28	500 00	********	********	********	139 04	69520 73	1 00	B =	-0 00	500 00	0 27	0.28				
410	750 00	0 24	750 00	0 24	750 00	********	********	********	181 36	*********	1 00	C =	4400 00	1000.00	0 23	0 23				
411	1000 00	0 23	1000 00	0 23	1000 00	********	********	********	225 57	*********	1 00	D =	0 29	1500 00	0 19	0 20				
412	1500 00	0 20	1500 00	0 20	1500 00	********	********	********	294 21	*********	1 00	E =	*********	2000.00	0 16	0 16				
413	2000 00	0 16	2000 00	0 16	2000 00	********	********	********	319.36	*********	1.00			2500 00	0 13	0 13				
414	2500.00	0 13	2500 00	0 13	2500 00	********	********	********	322.41	*********	1 00	a =	0 32	3000.00	0 11	0 10				
415	3000.00	0.10	3000.00	0 10	3000 00	********	********	********	312.58	*********	1.00	b =	-0 00	3500 00	0 09	0 09				
416	3500.00	0.09	3500.00	0.09	3500 00	********	********	********	301.23	*********	1 00	c =	0.00	4000.00	0 07	0.07				
417	4000.00	0.07	4000.00	0.07	4000 00	********	********	********	275 65	*********	1.00			2660.00	0 12					
418		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
419		500.00		1.49	18750 00	********	********	********	********	*********	9.00	ABgs3 = (ABCO2+ABH2O)(1-CSO1)								
420				Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.22						
421												ABCO2 = (EMCO2 @ Ts. P*L*Ts/Tg)*(Tg/Ts).65								
422														0.11						
423	CO2S3	500 00	1000.00	1500 00	2000 00	2500.00	3000 00	3500.00	*******			ABH2O = (EMH2O @ Ts. P*L*Ts/Tg)*(Tg/Ts).45								
424	---------	--------	--------	--------	--------	--------	--------	--------	--------					0.12						
425	a	0.08	0.07	0.08	0.07	0.06	0.04	0.04	0.03											
426	b	0.11	0.10	0.10	0.12	0.11	0.10	0.08	0.07			Tg =		2660 00	plo2 =	0 61				
427	c	-0.03	-0.03	-0.03	-0 03	-0.03	-0.02	-0.02	-0.02				Tg =	2660.00	Csog2 =	0.06				
428																				
429		Y=Emg	X=T																	
430	L=	0.61		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	Y calc	Y act=Eg		
431	500 00	0.14	500.00	0 14	500.00	********	********	********	69.15	34575.57	1.00	B =	-0.00	B =	-0.00	500.00	0 14	0 14		
432	1000.00	0 12	1000 00	0 12	1000 00	********	********	********	117.14	*********	1.00	C =	2500 00	C =	6500 00	1000.00	0 12	0 12		
433	1500 00	0 13	1500 00	0 13	1500 00	********	********	********	188.60	*********	1.00	D =	0.13	D =	0 20	1500 00	0 12	0 13		
434	2000 00	0 13	2000 00	0 13	2000 00	********	********	********	261 47	*********	1 00	E =	*********	E =	*********	2000 00	0 13	0 13		
435		---------	--------	--------	--------	--------	--------	--------	------	--------	--------					2500 00	0 11	0 11		
436		500 00		0 51	5000 00	********	********	********	636 36	*********	4 00	a =	0 16	a =	0 24	3000 00	0 10	0.10		
437				Y	X	X#2	X#3	X#4	XY	X#2Y	N	b =	-0.00	b =	-0 00	3500 00	0 08	0 08		
438												c =	0.00	c =	0 00	4000 00	0 06	0.06		
439	L=	0 61		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					2660 00	0 11			
440	2500 00	0 11	2500 00	0 11	2500.00	********	********	********	287 01	*********	1 00									

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
441			500.00		1.86	18750.00	************	************	************	3029.17	*********	9.00	ABgs) = (ABCO2+ABH2O)(1-CSO1)								
442					Y	X	X#2	X#3	X#4	XY	X#2Y	N			0.26						
443													ABCO2 = (EMCO2 @ Ts. P*L*Ts/Tg)*(Tg/Ts) .65								
444															0.13						
445	CO2S)		500.00	1000.00	1500.00	2000.00	2500.00	3000.00	3500.00	4000.00			ABH2O = (EWH2O @ Ts. P*L*Ts/Tg)*(Tg/Ts) .45								
446	-----------		--------	--------	--------	--------	--------	--------	--------	--------					0.16						
447	a		0.08	0.07	0.08	0.07	0.06	0.04	0.04	0.03											
448	b		0.11	0.10	0.10	0.12	0.11	0.10	0.08	0.07			Tg =		2660.00	plo3 =	0.91				
449	c		-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02				Tg =	2660.00	Csog) =	0.08				
450																					
451			Y=Emg	X=T																	
452		L=	0.91		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N	A =	0.00	A =	0.00	X=T	V calc	Y act=Eg		
453		500.00	0.16	500.00	0.16	500.00	************	************	************	77.84	38921.48	1.00	B =	-0.00	B =	-0.00	500.00	0.15	0.16		
454		1000.00	0.14	1000.00	0.14	1000.00	************	************	************	135.04	135037.73	1.00	C =	2500.00	C =	6500.00	1000.00	0.14	0.14		
455		1500.00	0.14	1500.00	0.14	1500.00	************	************	************	214.73	322092.47	1.00	D =	0.15	D =	0.24	1500.00	0.14	0.14		
456		2000.00	0.15	2000.00	0.15	2000.00	************	************	************	303.45	606891.48	1.00	E =	*********	E =	***********	2000.00	0.15	0.15		
457			-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------					2500.00	0.14	0.14		
458			500.00		0.59	5000.00	************	************	************	731.05	*********	4.00	a =	0.18	a =	0.27	3000.00	0.11	0.11		
459					Y	X	X#2	X#3	X#4	XY	X#2Y	. N	b =	-0.00	b =	-0.00	3500.00	0.09	0.09		
460													c =	0.00	c =	0.00	4000.00	0.07	0.07		
461		L=	0.91		Y=Emg	X=T	X^2	X^3	X^4	XY	X^2Y	N					2660.00	0.13			
462		2500.00	0.14	2500.00	0.14	2500.00	************	************	************	339.69	849212.78	1.00									
463		3000.00	0.11	3000.00	0.11	3000.00	************	************	************	342.17	*********	1.00									
464		3500.00	0.09	3500.00	0.09	3500.00	************	************	************	323.70	*********	1.00									
465		4000.00	0.07	4000.00	0.07	4000.00	************	************	************	295.31	*********	1.00									
466			-----------	--------	--------	--------	--------	--------	--------	-------	--------	--------									
467			500.00		0.42	13000.00	************	************	************	1300.87	*********	4.00									
468					Y	X	X#2	X#3	X#4	XY	X#2Y	N									
469	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************	************					

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN A	AP
441	3000 00	0 10	3000 00	0 10	3000 00	*********	*********	*********	285 87	*********	1 00									
442	3500 00	0.08	3500 00	0.08	3500 00	*********	*********	*********	269 37	*********	1 00									
443	4000 00	0 06	4000 00	0.06	4000.00	*********	*********	*********	244.25	*********	1 00									
444		---------	--------	--------	--------	--------	--------	--------	------	--------	--------									
445		500 00		0.35	13000.00	*********	*********	*********	*********	*********	4 00									
446				Y	X	X*2	X*3	X*4	XY	X*2Y	N									
447	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********	*********					
448																				
449																				
450																				
451																				
452																				
453																				
454																				
455																				
456																				
457																				
458																				
459																				
460																				
461																				
462																				
463																				
464																				
465																				
466																				
467																				
468																				
469																				

Appendix G

Program Listing for Gas Database Regression Analysis

	O	P	Q	R	S	T	U	V	W	X	Y
1											
2											
3											
4											
5	H_2O										
6											
7											
8	CONST	500	1000	1500	2000	2500	3000	3500	4000	750	
9	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------	
10	a	0.193360	0.136173	0.109983	0.082221	0.057915	0.044245	0.034452	0.024206	0.150427	
11	b	0.140591	0.144277	0.139809	0.129614	0.116838	0.099847	0.083375	0.074278	0.146890	
12	c	-0.01491	-0.01638	-0.01478	-0.01381	-0.01258	-0.01027	-0.00838	-0.00771	-0.01723	
13											
14		Y=EMg	X=T								
15	L=	5		Y=EMg	X=T	X^2	X^3	X^4	XY	X^2Y	N
16	500	0.523517	500	0.523517	500	250000	1.3E+08	6.2E+10	261.7587	130879.3	1
17	750	0.453961	750	0.453961	750	562500	4.2E+08	3.2E+11	340.4708	255353.1	1
18	1000	0.447921	1000	0.447921	1000	1000000	1.0E+09	1.0E+12	447.9210	447921.0	1
19	1500	0.439369	1500	0.439369	1500	2250000	3.4E+09	5.1E+12	659.0545	988581.8	1
20	2000	0.385022	2000	0.385022	2000	4000000	8.0E+09	1.6E+13	770.0440	1540088.	1
21	2500	0.327484	2500	0.327484	2500	6250000	1.6E+10	3.9E+13	818.7107	2046776.	1
22	3000	0.286547	3000	0.286547	3000	9000000	2.7E+10	8.1E+13	859.6425	2578927.	1
23	3500	0.241829	3500	0.241829	3500	12250000	4.3E+10	1.5E+14	846.4041	2962414.	1
24	4000	0.202614	4000	0.202614	4000	16000000	6.4E+10	2.6E+14	810.4573	3241829.	1
25		---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
26		500		3.308267	18750	51562500	1.6E+11	5.5E+14	5814.464	14192772	9
27				Y	X	X#2	X#3	X#4	XY	X#2Y	N
28											
29		A =	-0.00000				X=T	Y calc	Y act=Eg		Y calc
30		B =	-0.00008				500	0.501608	0.523517		0.338609
31		C =	4400				750	0.481372	0.453961		0.290875
32		D =	0.547211				1000	0.460928	0.447921		0.250150
33		E =	-3437500				1500	0.419410	0.439369		0.216436
34							2000	0.377054	0.385022		0.175279
35		a =	0.541449				2500	0.333860	0.327484		0.145563
36		b =	-0.00007				3000	0.289827	0.286547		0.120009
37		c =	-0.00000				3500	0.244957	0.241829		0.098618
38							4000	0.199248	0.202614		
39											

AB AC AD AE AF AG AH AI AJ AK AL

EMISSIVITY OF H2O: ACTUAL VS ESTIMATED

	FT*ATM							TEMPERATURE DEGREES R								
	P*L	500	500	500	750	750	750	1000	1000	1000	1500	1500	1500	2000	2000	2000
		ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELATA
LL =	0.2	0.19	0.210042	-10.55%	0.15	0.189274	-26.18%	0.13	0.169841	-30.65%	0.115	0.134988	-17.38%	0.088	0.105482	-19.87
	0.3	0.23	0.223805	2.69%	0.185	0.202912	-9.68%	0.175	0.183296	-4.74%	0.14	0.147895	-5.64%	0.115	0.117604	-2.26
	0.4	0.25	0.237240	5.10%	0.205	0.216229	-5.48%	0.19	0.196436	-3.39%	0.165	0.160506	2.72%	0.135	0.129451	4.11
	0.6	0.29	0.263129	9.27%	0.25	0.241898	3.24%	0.235	0.221772	5.63%	0.2	0.184835	7.58%	0.16	0.152320	4.80
	0.8	0.31	0.287710	7.19%	0.275	0.266282	3.17%	0.26	0.245850	5.44%	0.23	0.207976	9.58%	0.19	0.174089	8.37
	1	0.33	0.310982	5.76%	0.3	0.289380	3.54%	0.28	0.268671	4.05%	0.25	0.229929	8.03%	0.21	0.194757	7.26
	1.5	0.38	0.363437	4.36%	0.34	0.341501	-0.44%	0.325	0.320219	1.47%	0.295	0.279611	5.22%	0.25	0.241614	3.35
	2	0.41	0.407712	0.56%	0.36	0.385588	-7.11%	0.35	0.363905	-3.97%	0.32	0.321866	-0.58%	0.285	0.281593	1.20
	3	0.46	0.471726	-2.55%	0.42	0.449656	-7.06%	0.4	0.427693	-6.92%	0.38	0.384091	-1.08%	0.33	0.340922	-3.31
	5	0.53	0.501608	5.36%	0.46	0.481372	-4.65%	0.455	0.460928	-1.30%	0.445	0.419410	5.75%	0.39	0.377054	3.32
				5.34%			7.05%			6.76%			6.36%			5.79

P*L	2500	2500	2500	3000	3000	3000	3500	3500	3500	4000	4000	4000
	ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELATA	ACTUAL	ESTIMATED	DELTA
0.2	0.065	0.081	-25.11%	0.05	0.063	-25.03%	0.039	0.049	-25.77%	0.03	0.041	-36.44%
0.3	0.088	0.092	-5.02%	0.07	0.072	-3.35%	0.053	0.057	-8.27%	0.042	0.048	-13.16%
0.4	0.105	0.103	1.65%	0.083	0.082	1.24%	0.067	0.066	2.18%	0.053	0.054	-1.85%
0.6	0.13	0.124	4.44%	0.108	0.101	6.90%	0.088	0.081	7.61%	0.07	0.066	5.04%
0.8	0.155	0.144	6.98%	0.125	0.118	5.38%	0.105	0.096	8.25%	0.085	0.078	7.77%
1	0.17	0.163	4.03%	0.14	0.135	3.48%	0.115	0.111	3.78%	0.098	0.090	8.41%
1.5	0.21	0.206	1.80%	0.177	0.173	2.01%	0.15	0.143	4.48%	0.12	0.116	3.56%
2	0.23	0.243	-5.69%	0.2	0.206	-3.18%	0.16	0.171	-7.11%	0.14	0.138	1.30%
3	0.29	0.298	-2.82%	0.24	0.256	-6.62%	0.2	0.214	-7.00%	0.17	0.173	-1.51%
5	0.33	0.334	-1.17%	0.29	0.290	0.06%	0.245	0.245	0.02%	0.205	0.199	2.81%
			5.87%			5.72%			7.45%			8.19%

	A	B	C	D	E	F	G	H	I	J
1										
2										
3										
4	H20		.{?}{Down}/XG\A~							
5										
6	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
7	500		0.19	0.2	0.04	0.008	0.0016	0.038	0.0076	1
8			0.23	0.3	0.09	0.027	0.0081	0.069	0.0207	1
9			0.25	0.4	0.16	0.064	0.0256	0.1	0.04	1
10			0.29	0.6	0.36	0.216	0.1296	0.174	0.1044	1
11			0.31	0.8	0.64	0.512	0.4096	0.248	0.1984	1
12			0.33	1	1	1	1	0.33	0.33	1
13			0.38	1.5	2.25	3.375	5.0625	0.57	0.855	1
14			0.41	2	4	8	16	0.82	1.64	1
15			0.46	3	9	27	81	1.38	4.14	1
16			0.53	5	25	125	625	2.65	13.25	1
17	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
18	500		3.38	14.8	42.54	165.202	728.637	6.379	20.5861	10
19			Y	X	X#2	X#3	X#4	XY	X#2Y	N
20										
21	A = -0.01491			T		X=Lm	Y calc	Y act=Eg		
22	B = 0.066708			500		0.2	0.220882	0.19		
23	C = 4.954584					0.3	0.234195	0.23		
24	D = 0.239271		Y=A+B*X=C*X*X			0.4	0.247211	0.25		
25	E = -3.07878					0.6	0.272346	0.29		
26						0.8	0.296289	0.31		
27	a = 0.193360					1	0.319039	0.33		
28	b = 0.140591					1.5	0.370695	0.38		
29	c = -0.01491					2	0.414895	0.41		
30						3	0.480926	0.46		
31	P*L	EMg				5	0.523517	0.53		
32	0.05	0.200352				2.5	0.451638			
33										
34	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
35	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
36	1000		0.13	0.2	0.04	0.008	0.0016	0.026	0.0052	1
37			0.175	0.3	0.09	0.027	0.0081	0.0525	0.01575	1
38			0.19	0.4	0.16	0.064	0.0256	0.076	0.0304	1
39			0.235	0.6	0.36	0.216	0.1296	0.141	0.0846	1
40			0.26	0.8	0.64	0.512	0.4096	0.208	0.1664	1
41			0.28	1	1	1	1	0.28	0.28	1
42			0.325	1.5	2.25	3.375	5.0625	0.4875	0.73125	1
43			0.35	2	4	8	16	0.7	1.4	1

	A	B	C	D	E	F	G	H	I	J
44			0.4	3	9	27	81	1.2	3.6	1
45			0.455	5	25	125	625	2.275	11.375	1
46	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
47	1000		2.8	14.8	42.54	165.202	728.637	5.446	17.6886	10
48			Y	X	X#2	X#3	X#4	XY	X#2Y	N
49										
50	A = -0.01638			T		X=Lm	Y calc	Y act=Eg		
51	B = 0.063093			1000		0.2	0.164373	0.13		
52	C = 4.954584					0.3	0.177982	0.175		
53	D = 0.186621			Y=A+B*X=C*X*X		0.4	0.191263	0.19		
54	E = -3.07878					0.6	0.216841	0.235		
55						0.8	0.241108	0.26		
56	a = 0.136173					1	0.264065	0.28		
57	b = 0.144277					1.5	0.315722	0.325		
58	c = -0.01638					2	0.359186	0.35		
59						3	0.421535	0.4		
60	P*L	EMg				5	0.447921	0.455		
61	0.05	0.200352								
62										
63										
64	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
65										
66	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
67	1500		0.115	0.2	0.04	0.008	0.0016	0.023	0.0046	1
68			0.14	0.3	0.09	0.027	0.0081	0.042	0.0126	1
69			0.165	0.4	0.16	0.064	0.0256	0.066	0.0264	1
70			0.2	0.6	0.36	0.216	0.1296	0.12	0.072	1
71			0.23	0.8	0.64	0.512	0.4096	0.184	0.1472	1
72			0.25	1	1	1	1	0.25	0.25	1
73			0.295	1.5	2.25	3.375	5.0625	0.4425	0.66375	1
74			0.32	2	4	8	16	0.64	1.28	1
75			0.38	3	9	27	81	1.14	3.42	1
76			0.445	5	25	125	625	2.225	11.125	1
77	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
78	1500		2.54	14.8	42.54	165.202	728.637	5.1325	17.00155	10
79			Y	X	X#2	X#3	X#4	XY	X#2Y	N
80										
81	A = -0.01478			T		X=Lm	Y calc	Y act=Eg		
82	B = 0.066548			1500		0.2	0.137354	0.115		
83	C = 4.954584					0.3	0.150595	0.14		
84	0 = 0.155507			Y=A+B*X=C*X*X		0.4	0.163541	0.165		
85	E = -3.07878					0.6	0.188546	0.2		
86						0.8	0.212367	0.23		

	A	B	C	0	E	F	G	H	I	J
87	a =	0.109983				1	0.235006	0.25		
88	b =	0.139809				1.5	0.286428	0.295		
89	c =	-0.01478				2	0.330456	0.32		
90						3	0.396333	0.38		
91	P*L	EMg				5	0.439369	0.445		
92	0.05	0.200352								
93										
94	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
95										
96	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
97	2000		0.088	0.2	0.04	0.008	0.0016	0.0176	0.00352	1
98			0.115	0.3	0.09	0.027	0.0081	0.0345	0.01035	1
99			0.135	0.4	0.16	0.064	0.0256	0.054	0.0216	1
100			0.16	0.6	0.36	0.216	0.1296	0.096	0.0576	1
101			0.19	0.8	0.64	0.512	0.4096	0.152	'0.1216	1
102			0.21	1	1	1	1	0.21	0.21	1
103			0.25	1.5	2.25	3.375	5.0625	0.375	0.5625	1
104			0.285	2	4	8	16	0.57	1.14	1
105			0.33	3	9	27	81	0.99	2.97	1
106			0.39	5	25	125	625	1.95	9.75	1
107	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
108	2000		2.153	14.8	42.54	165.202	728.637	4.4491	14.84717	10
109			Y	X	X#2	X#3	X#4	XY	X#2Y	N
110										
111	A =	-0.01381		T		X=Lm	Y calc	Y act=Eg		
112	B =	0.061187		2000		0.2	0.107592	0.088		
113	C =	4.954584				0.3	0.119863	0.115		
114	0 =	0.124742		Y=A+B*X=C*X*X		0.4	0.131858	0.135		
115	E =	-3.07878				0.6	0.155018	0.16		
116						0.8	0.177074	0.19		
117	a =	0.082221				1	0.198025	0.21		
118	b =	0.129614				1.5	0.245569	0.25		
119	c =	-0.01381				2	0.286207	0.285		
120						3	0.346767	0.33		
121	P*L	EMg				5	0.385022	0.39		
122	0.05	0.200352								
123	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
124										
125	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
126	2500		0.065	0.2	0.04	0.008	0.0016	0.013	0.0026	1
127			0.088	0.3	0.09	0.027	0.0081	0.0264	0.00792	1
128			0.105	0.4	0.16	0.064	0.0256	0.042	0.0168	1
129			0.13	0.6	0.36	0.216	0.1296	0.078	0.0468	1

	A	B	C	D	E	F	G	H	I	J
130			0.155	0.8	0.64	0.512	0.4096	0.124	0.0992	1
131			0.17	1	1	1	1	0.17	0.17	1
132			0.21	1.5	2.25	3.375	5.0625	0.315	0.4725	1
133			0.23	2	4	8	16	0.46	0.92	1
134			0.29	3	9	27	81	0.87	2.61	1
135			0.33	5	25	125	625	1.65	8.25	1
136	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
137	2500		1.773	14.8	42.54	165.202	728.637	3.7484	12.59582	10
138			Y	X	X#2	X#3	X#4	XY	X#2Y	N
139										
140	A =	-0.01258		T		X=Lm	Y calc	Y act=Eg		
141	B =	0.054485		2500		0.2	0.080779	0.065		
142	C =	4.954584				0.3	0.091834	0.088		
143	0 =	0.096661		Y=A+B*X=C*X*X		0.4	0.102637	0.105		
144	E =	-3.07878				0.6	0.123487	0.13		
145						0.8	0.143331	0.155		
146	a =	0.057915				1	0.162168	0.17		
147	b =	0.116838				1.5	0.204857	0.21		
148	c =	-0.01258				2	0.241252	0.23		
149						3	0.295166	0.29		
150	P*L	EMg				5	0.327484	0.33		
151	0.05	0.200352								
152										
153	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
154	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
155	3000		0.05	0.2	0.04	0.008	0.0016	0.01	0.002	1
156			0.07	0.3	0.09	0.027	0.0081	0.021	0.0063	1
157			0.083	0.4	0.16	0.064	0.0256	0.0332	0.01328	1
158			0.108	0.6	0.36	0.216	0.1296	0.0648	0.03888	1
159			0.125	0.8	0.64	0.512	0.4096	0.1	0.08	1
160			0.14	1	1	1	1	0.14	0.14	1
161			0.177	1.5	2.25	3.375	5.0625	0.2655	0.39825	1
162			0.2	2	4	8	16	0.4	0.8	1
163			0.24	3	9	27	81	0.72	2.16	1
164			0.29	5	25	125	625	1.45	7.25	1
165	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
166	3000		1.483	14.8	42.54	165.202	728.637	3.2045	10.88871	10
167			Y	X	X#2	X#3	X#4	XY	X#2Y	N
168										
169	A =	-0.01027		T		X=Lm	Y calc	Y act=Eg		
170	B =	0.048927		3000		0.2	0.063804	0.05		
171	C =	4.954584				0.3	0.073275	0.07		
172	D =	0.075887		Y=A+B*X=C*X*X		0.4	0.082540	0.083		

	A	B	C	D	E	F	G	H	I	J
173	E =	-3.07878				0.6	0.100454	0.108		
174						0.8	0.117546	0.125		
175	a =	0.044245				1	0.133815	0.14		
176	b =	0.099847				1.5	0.170893	0.177		
177	c =	-0.01027				2	0.202831	0.2		
178						3	0.251291	0.24		
179	P*L	EMg				5	0.286547	0.29		
180	0.05	0.200352								
181			--------	--------	--------	--------	--------	--------	--------	--------
182	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
183	3500		0.039	0.2	0.04	0.008	0.0016	0.0078	0.00156	1
184			0.053	0.3	0.09	0.027	0.0081	0.0159	0.00477	1
185			0.067	0.4	0.16	0.064	0.0256	0.0268	0.01072	1
186			0.088	0.6	0.36	0.216	0.1296	0.0528	0.03168	1
187			0.105	0.8	0.64	0.512	0.4096	0.084	0.0672	1
188			0.115	1	1	1	1	0.115	0.115	1
189			0.15	1.5	2.25	3.375	5.0625	0.225	0.3375	1
190			0.16	2	4	8	16	0.32	0.64	1
191			0.2	3	9	27	81	0.6	1.8	1
192			0.245	5	25	125	625	1.225	6.125	1
193	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
194	3500		1.222	14.8	42.54	165.202	728.637	2.6723	9.13343	10
195			Y	X	X#2	X#3	X#4	XY	X#2Y	N
196										
197	A =	-0.00838		T		X=Lm	Y calc	Y act=Eg		
198	B =	0.041855		3500		0.2	0.050792	0.039		
199	C =	4.954584				0.3	0.058711	0.053		
200	D =	0.060253		Y=A+B*X=C*X*X		0.4	0.066462	0.067		
201	E =	-3.07878				0.6	0.081461	0.088		
202						0.8	0.095790	0.105		
203	a =	0.034452				1	0.109448	0.115		
204	b =	0.083375				1.5	0.140661	0.15		
205	c =	-0.00838				2	0.167683	0.16		
206						3	0.209159	0.2		
207	P*L	EMg				5	0.241829	0.245		
208	0.05	0.200352								
209										
210										
211										
212										
213										
214										
215										

	A	B	C	D	E	F	G	H	I	J
216										
217										
218										
219										
220										
221										
222										
223										
224										
225										
226										
227										
228										
229	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
230	T, K		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
231	4000		0.03	0.2	0.04	0.008	0.0016	0.006	0.0012	1
232			0.042	0.3	0.09	0.027	0.0081	0.0126	0.00378	1
233			0.053	0.4	0.16	0.064	0.0256	0.0212	0.00848	1
234			0.07	0.6	0.36	0.216	0.1296	0.042	0.0252	1
235			0.085	0.8	0.64	0.512	0.4096	0.068	0.0544	1
236			0.098	1	1	1	1	0.098	0.098	1
237			0.12	1.5	2.25	3.375	5.0625	0.18	0.27	1
238			0.14	2	4	8	16	0.28	0.56	1
239			0.17	3	9	27	81	0.51	1.53	1
240			0.205	5	25	125	625	1.025	5.125	1
241	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
242	4000		1.013	14.8	42.54	165.202	728.637	2.2428	7.67606	10
243			Y	X	X#2	X#3	X#4	XY	X#2Y	N
244										
245	A = -0.00771			T		X=Lm	Y calc	Y act=Eg		
246	B = 0.036032			4000		0.2	0.038753	0.03		
247	C = 4.954584					0.3	0.045795	0.042		
248	D = 0.047972			Y=A+B*X=C*X*X		0.4	0.052682	0.053		
249	E = -3.07878					0.6	0.065994	0.07		
250						0.8	0.078688	0.085		
251	a = 0.024206					1	0.090765	0.098		
252	b = 0.074278					1.5	0.118255	0.12		
253	c = -0.00771					2	0.141885	0.14		
254										
255	P*L	EMg								
256	0.05	0.200352								
257	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
258	T, K		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N

	A	B	C	D	E	F	G	H	I	J
259	750		0.15	0.2	0.04	0.008	0.0016	0.03	0.006	1
260			0.185	0.3	0.09	0.027	0.0081	0.0555	0.01665	1
261			0.205	0.4	0.16	0.064	0.0256	0.082	0.0328	1
262			0.25	0.6	0.36	0.216	0.1296	0.15	0.09	1
263			0.275	0.8	0.64	0.512	0.4096	0.22	0.176	1
264			0.3	1	1	1	1	0.3	0.3	1
265			0.34	1.5	2.25	3.375	5.0625	0.51	0.765	1
266			0.36	2	4	8	16	0.72	1.44	1
267			0.42	3	9	27	81	1.26	3.78	1
268			0.46	5	25	125	625	2.3	11.5	1
269	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
270	750		2.945	14.8	42.54	165.202	728.637	5.6275	18.10645	10
271			Y	X	X#2	X#3	X#4	XY	X#2Y	N
272										
273	A = -0.01723			T		X=Lm	Y calc	Y act=Eg		
274	B = 0.061489			750		0.2	0.179115	0.15		
275	C = 4.954584					0.3	0.192942	0.185		
276	0 = 0.203495			Y=A+B*X=C*X*X		0.4	0.206425	0.205		
277	E = -3.07878					0.6	0.232356	0.25		
278						0.8	0.256908	0.275		
279	a = 0.150427					1	0.280080	0.3		
280	b = 0.146890					1.5	0.331980	0.34		
281	c = -0.01723					2	0.375261	0.36		
282						3	0.435968	0.42		
283						5	0.453961	0.46		

	M	N	O	P	Q	R	S	T	U	V
1	CONST	500	1000	1500	2000	2500	3000	3500	4000	4500
2	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
3	a	0.113014	0.085994	0.097287	0.094390	0.077821	0.061488	0.049351	0.039099	0.072831
4	b	0.038437	0.045063	0.047224	0.059833	0.060663	0.056025	0.045795	0.036061	0.140905
5	c	-0.00432	-0.00570	-0.00544	-0.00743	-0.00717	-0.00637	-0.00480	-0.00344	-0.04336
6										
7										
8										
9	CO_2									
10										
11										
12		Y=EMg	X=T							
13	L=	5		Y=EMg	X=T	X^2	X^3	X^4	XY	X^2Y
14	500	0.197053	500	0.197053	500	250000	1.3E+08	6.2E+10	98.52694	49263.47
15	1000	0.168575	1000	0.168575	1000	1000000	1.0E+09	1.0E+12	168.5753	168575.3
16	1500	0.197184	1500	0.197184	1500	2250000	3.4E+09	5.1E+12	295.7766	443664.9
17	2000	0.207588	2000	0.207588	2000	4000000	8.0E+09	1.6E+13	415.1764	830352.9
18		--------	--------	--------	--------	--------	--------	--------	--------	--------
19		500		0.770401	5000	7500000	1.3E+10	2.2E+13	978.0554	1491856.
20				Y	X	X#2	X#3	X#4	XY	X#2Y
21										
22	L=	5		Y=EMg	X=T	X^2	X^3	X^4	XY	X^2Y
23	2500	0.201876	2500	0.201876	2500	6250000	1.6E+10	3.9E+13	504.6909	1261727.
24	3000	0.182318	3000	0.182318	3000	9000000	2.7E+10	8.1E+13	546.9544	1640863.
25	3500	0.158272	3500	0.158272	3500	12250000	4.3E+10	1.5E+14	553.9544	1938840.
26	4000	0.133189	4000	0.133189	4000	16000000	6.4E+10	2.6E+14	532.7577	2131031.
27		--------	--------	--------	--------	--------	--------	--------	--------	--------
28		500		0.675656	13000	43500000	1.5E+11	5.3E+14	2138.357	6972462.
29				Y	X	X#2	X#3	X#4	XY	X#2Y
30										
31		A =	0.000000		A =	-0.00000	X=T	Y calc	Y act=Eg	
32		B =	0.000012		B =	-0.00004	500	0.193289	0.197053	
33		C =	2500		C =	6500	1000	0.179869	0.168575	
34		D =	0.177547		D =	0.318483	1500	0.185890	0.197184	
35		E =	-1250000		E =	-1.0E+07	2000	0.211352	0.207588	
36							2500	0.202048	0.201876	
37		a =	0.226150		a =	0.261851	3000	0.181800	0.182318	
38		b =	-0.00008		b =	-0.00001	3500	0.158790	0.158272	
39		c =	0.000000		c =	-0.00000	4000	0.133016	0.133189	

	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1			ALT Z											
2		/CL~LM~{Calc}{GoTo}LL~/RVC~~{GoTo}L~{Down}/RNCL~{Bs}~												
3		{GoTo}LL~/M{End}{Down}~{Down}~{Down}												
4	ALT X	/M~{End}{Right}{Right}~												
5		{Down}/M{End}{Down}~{Up}~{Up}												
6			/RNCLL~{Bs}~											
7	EMISSIVITY OF CO2: ACTUAL VS ESTIMATED													
8		FT*ATM					TEMPERATURE DEGREES R							
9		P*L	500	500	500	1000	1000	1000	1500	1500	1500	2000	2000	2000
10		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
11	LL		ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA
12														
13		0.2	0.108	0.118045	-9.30%	0.085	0.102230	-20.27%	0.095	0.099063	-4.28%	0.095	0.108543	-14.26%
14		0.3	0.12	0.121737	-1.45%	0.095	0.106256	-11.85%	0.108	0.103707	3.97%	0.108	0.114090	-5.64%
15		0.4	0.13	0.125339	3.58%	0.105	0.110180	-4.93%	0.12	0.108231	9.81%	0.12	0.119492	0.42%
16		0.6	0.14	0.132272	5.52%	0.115	0.117720	-2.37%	0.127	0.116917	7.94%	0.13	0.129861	0.11%
17		0.8	0.15	0.138843	7.44%	0.125	0.124850	0.12%	0.135	0.125120	7.32%	0.145	0.139650	3.69%
18		1	0.152	0.145052	4.57%	0.132	0.131571	0.32%	0.145	0.132840	8.39%	0.155	0.148860	3.96%
19		1.5	0.165	0.158993	3.64%	0.142	0.146577	-3.22%	0.16	0.150029	6.23%	0.17	0.169349	0.38%
20		2	0.17	0.170673	-0.40%	0.152	0.159021	-4.62%	0.17	0.164202	3.41%	0.18	0.186215	-3.45%
21		3	0.18	0.187253	-4.03%	0.162	0.176221	-8.78%	0.18	0.183498	-1.94%	0.2	0.209083	-4.54%
22		5	0.2	0.193289	3.36%	0.171	0.179869	-5.19%	0.2	0.185890	7.05%	0.21	0.211352	-0.64%
23		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
24					4.33%			6.17%			6.03%			3.71%
25														
26		L	2500	2500	2500	3000	3000	3000	3500	3500	3500	4000	4000	4000
27		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
28			ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA	ACTUAL	ESTIMATED	DELTA
29														
30		0.2	0.08	0.089610	-12.01%	0.064	0.072608	-13.45%	0.052	0.058148	-11.82%	0.04	0.046230	-15.58%
31		0.3	0.09	0.095346	-5.94%	0.074	0.077808	-5.15%	0.06	0.062571	-4.29%	0.048	0.049636	-3.41%
32		0.4	0.1	0.100937	-0.94%	0.083	0.082884	0.14%	0.067	0.066896	0.15%	0.053	0.052974	0.05%
33		0.6	0.119	0.111687	6.15%	0.096	0.092661	3.48%	0.079	0.075247	4.75%	0.062	0.059445	4.12%
34		0.8	0.128	0.121859	4.80%	0.108	0.101941	5.61%	0.087	0.083203	4.36%	0.069	0.065645	4.86%
35		1	0.138	0.131453	4.74%	0.119	0.110723	6.96%	0.094	0.090763	3.44%	0.076	0.071573	5.82%
36		1.5	0.158	0.152912	3.22%	0.133	0.130499	1.88%	0.11	0.107929	1.88%	0.088	0.085202	3.18%
37		2	0.168	0.170762	-1.64%	0.148	0.147164	0.56%	0.12	0.122620	-2.18%	0.097	0.097132	-0.14%
38		3	0.185	0.195630	-5.75%	0.163	0.171157	-5.00%	0.138	0.144577	-4.77%	0.11	0.115892	-5.36%
39		5	0.205	0.202048	1.44%	0.185	0.181800	1.73%	0.16	0.158790	0.76%	0.135	0.133016	1.47%
40		--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
41					4.66%			4.40%			3.84%			4.40%

	A	B	C	D	E	F	G	H	I	J
1	C02		.(?)(Down)/XG\A~							
2										
3	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
4	500		0.108	0.2	0.04	0.008	0.0016	0.0216	0.00432	1
5			0.12	0.3	0.09	0.027	0.0081	0.036	0.0108	1
6			0.13	0.4	0.16	0.064	0.0256	0.052	0.0208	1
7			0.14	0.6	0.36	0.216	0.1296	0.084	0.0504	1
8			0.15	0.8	0.64	0.512	0.4096	0.12	0.096	1
9			0.152	1	1	1	1	0.152	0.152	1
10			0.165	1.5	2.25	3.375	5.0625	0.2475	0.37125	1
11			0.17	2	4	8	16	0.34	0.68	1
12			0.18	3	9	27	81	0.54	1.62	1
13			0.2	5	25	125	625	1	5	1
14	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
15	500		1.515	14.8	42.54	165.202	728.637	2.5931	8.00557	10
16			Y	X	X#2	X#3	X#4	XY	X#2Y	N
17										
18	A = -0.00432			T		X=Lm	Y calc	Y act=Eg		
19	B = 0.017004			500		0.2	0.120529	0.108		
20	C = 4.954584					0.3	0.124156	0.12		
21	D = 0.126333			Y=A+B*X=C*X*X		0.4	0.127697	0.13		
22	E = -3.07878					0.6	0.134520	0.14		
23						0.8	0.140996	0.15		
24	a = 0.113014					1	0.147126	0.152		
25	b = 0.038437					1.5	0.160938	0.165		
26	c = -0.00432					2	0.172586	0.17		
27						3	0.189394	0.18		
28	P*L	EMg				5	0.197053	0.2		
29	0.05	0.114925				2.5	0.182071			
30										
31	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
32	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
33	1000		0.085	0.2	0.04	0.008	0.0016	0.017	0.0034	1
34			0.095	0.3	0.09	0.027	0.0081	0.0285	0.00855	1
35			0.105	0.4	0.16	0.064	0.0256	0.042	0.0168	1
36			0.115	0.6	0.36	0.216	0.1296	0.069	0.0414	1
37			0.125	0.8	0.64	0.512	0.4096	0.1	0.08	1
38			0.132	1	1	1	1	0.132	0.132	1
39			0.142	1.5	2.25	3.375	5.0625	0.213	0.3195	1

	A	B	C	D	E	F	G	H	I	J
40			0.152	2	4	8	16	0.304	0.608	1
41			0.162	3	9	27	81	0.486	1.458	1
42			0.171	5	25	125	625	0.855	4.275	1
43	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
44	1000		1.284	14.8	42.54	165.202	728.637	2.2465	6.94265	10
45			Y	X	X#2	X#3	X#4	XY	X#2Y	N
46										
47	A =	-0.00570		T		X=Lm	Y calc	Y act=Eg		
48	B =	0.016775		1000		0.2	0.094778	0.085		
49	C =	4.954584				0.3	0.098999	0.095		
50	D =	0.103572		Y=A+B*X=C*X*X		0.4	0.103105	0.105		
51	E =	-3.07878				0.6	0.110976	0.115		
52						0.8	0.118390	0.125		
53	a =	0.085994				1	0.125348	0.132		
54	b =	0.045063				1.5	0.140742	0.142		
55	c =	-0.00570				2	0.153283	0.152		
56						3	0.169799	0.162		
57	P*L	EMg				5	0.168575	0.171		
58	0.05	0.114925								
59										
60										
61	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
62										
63	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
64	1500		0.095	0.2	0.04	0.008	0.0016	0.019	0.0038	1
65			0.108	0.3	0.09	0.027	0.0081	0.0324	0.00972	1
66			0.12	0.4	0.16	0.064	0.0256	0.048	0.0192	1
67			0.127	0.6	0.36	0.216	0.1296	0.0762	0.04572	1
68			0.135	0.8	0.64	0.512	0.4096	0.108	0.0864	1
69			0.145	1	1	1	1	0.145	0.145	1
70			0.16	1.5	2.25	3.375	5.0625	0.24	0.36	1
71			0.17	2	4	8	16	0.34	0.68	1
72			0.18	3	9	27	81	0.54	1.62	1
73			0.2	5	25	125	625	1	5	1
74	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
75	1500		1.44	14.8	42.54	165.202	728.637	2.5486	7.96984	10
76			Y	X	X#2	X#3	X#4	XY	X#2Y	N
77										
78	A =	-0.00544		T		X=Lm	Y calc	Y act=Eg		

	A	B	C	D	E	F	G	H	I	J
79	B =	0.020226		1500		0.2	0.106514	0.095		
80	C =	4.954584				0.3	0.110964	0.108		
81	D =	0.114064		Y=A+B*X=C*X*X		0.4	0.115305	0.12		
82	E =	-3.07878				0.6	0.123660	0.127		
83						0.8	0.131580	0.135		
84	a =	0.097287				1	0.139063	0.145		
85	b =	0.047224				1.5	0.155864	0.16		
86	c =	-0.00544				2	0.169940	0.17		
87						3	0.189920	0.18		
88	P*L	EMg				5	0.197184	0.2		
89	0.05	0.114925								
90										
91	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
92										
93	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
94	2000		0.095	0.2	0.04	0.008	0.0016	0.019	0.0038	1
95			0.108	0.3	0.09	0.027	0.0081	0.0324	0.00972	1
96			0.12	0.4	0.16	0.064	0.0256	0.048	0.0192	1
97			0.13	0.6	0.36	0.216	0.1296	0.078	0.0468	1
98			0.145	0.8	0.64	0.512	0.4096	0.116	0.0928	1
99			0.155	1	1	1	1	0.155	0.155	1
100			0.17	1.5	2.25	3.375	5.0625	0.255	0.3825	1
101			0.18	2	4	8	16	0.36	0.72	1
102			0.2	3	9	27	81	0.6	1.8	1
103			0.21	5	25	125	625	1.05	5.25	1
104	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
105	2000		1.513	14.8	42.54	165.202	728.637	2.7134	8.47982	10
106			Y	X	X#2	X#3	X#4	XY	X#2Y	N
107										
108	A =	-0.00743		T		X=Lm	Y calc	Y act=Eg		
109	B =	0.022977		2000		0.2	0.106060	0.095		
110	C =	4.954584				0.3	0.111671	0.108		
111	D =	0.117293		Y=A+B*X=C*X*X		0.4	0.117134	0.12		
112	E =	-3.07878				0.6	0.127613	0.13		
113						0.8	0.137497	0.145		
114	a =	0.094390				1	0.146785	0.155		
115	b =	0.059833				1.5	0.167404	0.17		
116	c =	-0.00743				2	0.184303	0.18		
117						3	0.206942	0.2		

	A	B	C	D	E	F	G	H	I	J
118	P*L	EMg				5	0.207588	0.21		
119	0.05	0.114925								
120	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
121										
122	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
123	2500		0.08	0.2	0.04	0.008	0.0016	0.016	0.0032	1
124			0.09	0.3	0.09	0.027	0.0081	0.027	0.0081	1
125			0.1	0.4	0.16	0.064	0.0256	0.04	0.016	1
126			0.119	0.6	0.36	0.216	0.1296	0.0714	0.04284	1
127			0.128	0.8	0.64	0.512	0.4096	0.1024	0.08192	1
128			0.138	1	1	1	1	0.138	0.138	1
129			0.158	1.5	2.25	3.375	5.0625	0.237	0.3555	1
130			0.168	2	4	8	16	0.336	0.672	1
131			0.185	3	9	27	81	0.555	1.665	1
132			0.205	5	25	125	625	1.025	5.125	1
133	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
134	2500		1.371	14.8	42.54	165.202	728.637	2.5478	8.10756	10
135			Y	X	X#2	X#3	X#4	XY	X#2Y	N
136										
137	A = -0.00717			T		X=Lm	Y calc	Y act=Eg		
138	B = 0.025136			2500		0.2	0.089667	0.08		
139	C = 4.954584					0.3	0.095375	0.09		
140	D = 0.099897			Y=A+B*X=C*X*X		0.4	0.100939	0.1		
141	E = -3.07878					0.6	0.111638	0.119		
142						0.8	0.121763	0.128		
143	a = 0.077821					1	0.131314	0.138		
144	b = 0.060663					1.5	0.152682	0.158		
145	c = -0.00717					2	0.170466	0.168		
146						3	0.195277	0.185		
147	P*L	EMg				5	0.201876	0.205		
148	0.05	0.114925								
149										
150	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------
151	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
152	3000		0.064	0.2	0.04	0.008	0.0016	0.0128	0.00256	1
153			0.074	0.3	0.09	0.027	0.0081	0.0222	0.00666	1
154			0.083	0.4	0.16	0.064	0.0256	0.0332	0.01328	1
155			0.096	0.6	0.36	0.216	0.1296	0.0576	0.03456	1
156			0.108	0.8	0.64	0.512	0.4096	0.0864	0.06912	1

	A	B	C	D	E	F	G	H	I	J
157			0.119	1	1	1	1	0.119	0.119	1
158			0.133	1.5	2.25	3.375	5.0625	0.1995	0.29925	1
159			0.148	2	4	8	16	0.296	0.592	1
160			0.163	3	9	27	81	0.489	1.467	1
161			0.185	5	25	125	625	0.925	4.625	1
162	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
163	3000		1.173	14.8	42.54	165.202	728.637	2.2407	7.22843	10
164			Y	X	X#2	X#3	X#4	XY	X#2Y	N
165										
166	A = -0.00637			T		X=Lm	Y calc	Y act=Eg		
167	B = 0.024455			3000		0.2	0.072438	0.064		
168	C = 4.954584					0.3	0.077722	0.074		
169	D = 0.081106			Y=A+B*X=C*X*X		0.4	0.082879	0.083		
170	E = -3.07878					0.6	0.092809	0.096		
171						0.8	0.102230	0.108		
172	a = 0.061488					1	0.111141	0.119		
173	b = 0.056025					1.5	0.131189	0.133		
174	c = -0.00637					2	0.148051	0.148		
175						3	0.172217	0.163		
176	P*L	EMg				5	0.182318	0.185		
177	0.05	0.114925								
178			--------	--------	--------	--------	--------	--------	--------	--------
179	T, R		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
180	3500		0.052	0.2	0.04	0.008	0.0016	0.0104	0.00208	1
181			0.06	0.3	0.09	0.027	0.0081	0.018	0.0054	1
182			0.067	0.4	0.16	0.064	0.0256	0.0268	0.01072	1
183			0.079	0.6	0.36	0.216	0.1296	0.0474	0.02844	1
184			0.087	0.8	0.64	0.512	0.4096	0.0696	0.05568	1
185			0.094	1	1	1	1	0.094	0.094	1
186			0.11	1.5	2.25	3.375	5.0625	0.165	0.2475	1
187			0.12	2	4	8	16	0.24	0.48	1
188			0.138	3	9	27	81	0.414	1.242	1
189			0.16	5	25	125	625	0.8	4	1
190	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
191	3500		0.967	14.8	42.54	165.202	728.637	1.8852	6.16582	10
192			Y	X	X#2	X#3	X#4	XY	X#2Y	N
193										
194	A = -0.00480			T		X=Lm	Y calc	Y act=Eg		
195	B = 0.022002			3500		0.2	0.058318	0.052		

	A	B	C	D	E	F	G	H	I	J
196	C =	4.954584				0.3	0.062657	0.06		
197	D =	0.064136		Y=A+B*X=C*X*X		0.4	0.066901	0.067		
198	E =	-3.07878				0.6	0.075099	0.079		
199						0.8	0.082914	0.087		
200	a =	0.049351				1	0.090344	0.094		
201	b =	0.045795				1.5	0.107239	0.11		
202	c =	-0.00480				2	0.121733	0.12		
203						3	0.143517	0.138		
204	P*L	EMg				5	0.158272	0.16		
205	0.05	0.114925								
206										
207										
208										
209	T, K		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
210	4000		0.04	0.2	0.04	0.008	0.0016	0.008	0.0016	1
211			0.048	0.3	0.09	0.027	0.0081	0.0144	0.00432	1
212			0.053	0.4	0.16	0.064	0.0256	0.0212	0.00848	1
213			0.062	0.6	0.36	0.216	0.1296	0.0372	0.02232	1
214			0.069	0.8	0.64	0.512	0.4096	0.0552	0.04416	1
215			0.076	1	1	1	1	0.076	0.076	1
216			0.088	1.5	2.25	3.375	5.0625	0.132	0.198	1
217			0.097	2	4	8	16	0.194	0.388	1
218			0.11	3	9	27	81	0.33	0.99	1
219			0.135	5	25	125	625	0.675	3.375	1
220										
221	4000		0.778	14.8	42.54	165.202	728.637	1.543	5.10788	10
222			Y	X	X#2	X#3	X#4	XY	X#2Y	N
223										
224	A =	-0.00344		T		X=Lm	Y calc	Y act=Eg		
225	B =	0.018974		4000		0.2	0.046173	0.04		
226	C =	4.954584				0.3	0.049607	0.048		
227	D =	0.049717		Y=A+B*X=C*X*X		0.4	0.052972	0.053		
228	E =	-3.07878				0.6	0.059495	0.062		
229						0.8	0.065741	0.069		
230	a =	0.039099				1	0.071712	0.076		
231	b =	0.036061				1.5	0.085432	0.088		
232	c =	-0.00344				2	0.097428	0.097		
233										
234	P*L	EMg								

	A	B	C	D	E	F	G	H	I	J
235	0.05	0.114925								
236	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
237	T, K		Y=EMg	X=P*L	X^2	X^3	X^4	XY	X^2Y	N
238	4500		0.045	0.1	0.01	0.001	0.0001	0.0045	0.00045	1
239			0.075	0.15	0.0225	0.003375	0.000506	0.01125	0.001687	1
240			0.1	0.2	0.04	0.008	0.0016	0.02	0.004	1
241			0.155	0.6	0.36	0.216	0.1296	0.093	0.0558	1
242			0.155	1	1	1	1	0.155	0.155	1
243			0.155	0.4	0.16	0.064	0.0256	0.062	0.0248	1
244			0.155	0.8	0.64	0.512	0.4096	0.124	0.0992	1
245			0.155	0.3	0.09	0.027	0.0081	0.0465	0.01395	1
246			0.155	1.5	2.25	3.375	5.0625	0.2325	0.34875	1
247			0.2	2	4	8	16	0.4	0.8	1
248	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
249	4500		1.35	7.05	8.5725	13.20637	22.63760	1.14875	1.503637	10
250			Y	X	X#2	X#3	X#4	XY	X#2Y	N
251										
252	A = -0.04336			T		X=Lm	Y calc	Y act=Eg		
253	B = 0.054688			4500		0.1	0.086488	0.045		
254	C = 1.988413					0.15	0.092992	0.075		
255	D = 0.096444			Y=A+B*X=C*X*X		0.2	0.099278	0.1		
256	E = -0.54458					0.6	0.141765	0.155		
257						1	0.170377	0.155		
258	a = 0.072831					0.4	0.122256	0.155		
259	b = 0.140905					0.8	0.157806	0.155		
260	c = -0.04336					0.3	0.111201	0.155		
261						1.5	0.186630	0.155		
262						2	0.181203	0.2		
263										

Appendix H

Nomenclature

Nomenclature

a	constant determined by the tube bundle configuration and the amount of leakage air normal to the tube bundle
a_i	weighting factor represents the fraction of black body energy in the emitting/absorbing wavenumber region associated with the absorption coefficient K_i
A	bounding surface area of the kiln volume
A_1	radiating surface area upon which F_{12} is based, sq. ft.
A_3	area of second layer of refractory, m^2
A'_f	new 'effective' area in the equation for radiant heat from the flame
A_i	surface area
C	0.193 for Re values of 4,000 to 40,000
C_p	heat capacity of the gas
d_o	burner nozzle diameter, ft
D	kiln diameter, ft.
D	outer kiln diameter, m
F	solid bed depth (of fill)
F/D	fill ratio of F devided by D
F_{12}	view factor between surface 1 and surface 2
F_{ij}	view factor from one surface area to another

F_{ij}	the fraction of radiation leaving the first surface which is intercepted by the second surface
G'_g	gas mass flux $Kg/m^2 hr$
h_{cd}	conductive heat transfer coefficient, $W/m^2 K$
h_{cdws}	HTC between the wall and solid bed
h_{cvgs}	convective HTC from the gas to the solid bed
h_{cvgw}	convective HTC from the gas to the wall (Eq. 5.0-1)
h_{cvsh}	outer shell convection HTC
h_r	radiant heat transfer coefficient (Eqn. 2-3.1), in Btu/hr sq ft R
h_{rad}	linearized radiative HTC for the outer shell
H_{air}	enthalpy of the entering combustion gas and excess air
ΔH_{solids}	change in enthalpy of the solids
ΔH_{gas}	change in enthalpy of the combustion gas and excess air
$I_{absorbed}$	amount of energy attenuated by the gas for each ray
$I_{initial}$	energy initially emitted or reflected
$I_{transmitted}$	energy that is transmitted through the gas to a solid surface.
k_s	solids thermal diffusivity, m^2/s
K	thermal conductivity of the gas, W/m
K_a	thermal conductivity of air W/m K
K_g	gas thermal conductivity W/m K

K_i	absorption coefficient (depends on the pressure and temperature of the gas)
K_s	solid thermal conductivity W/m K
K_i	thermal conductivity of refractory layer or shell, W m/m^2K
L	kiln length, m
L_m	<u>mean</u> beam length,, is an approximate representation of the geometry of an isothermal gas volume. Physically, the mean beam length is the radius of an equivalent gas hemisphere which radiates a flux to the center of its base equal to the average flux radiated to the area of interest by the actual volume of gas. (see Section 4.5)
$\dot{m}_o$	mass fired through the burner lb/hr
m_r	additional flow at distance x due to recirculation and entrainment
N	constant equal to 0.618
P or p	represents the specific or combined partial pressures of CO_2 and H_2O
P_r	Prandl number = $C_p\mu/K$
q_{cond}	heat conducted through kiln wall
q_r	radiant heat flow, Btu/hr
Q_{comb}	heat of combustion of the fuel
$Q_{shell\ loss}$	heat conducted through the wall and lost from the outer shell
Q_{gi}	heat absorbed by surface i from the gas

Q_i	rate at which the total radiation is emitted from a surface i
$Q_{i\ absorbed}$	heat absorbed by a surface i
Q_{ig}	energy originally emitted by surface i which is absorbed by the gas
Q_{ij}	energy originally emitted by surface i
Q_{ji}	heat absorbed by surface i from the other sufaces j
ΔQ_i	net radiant heat change for a surface (or the gas), (Eq. 4.2-2)
r_1	inner kiln radius, m
r_2	kiln radius for first layer of refractory, m
r_3	kiln radius for second layer of refractory, m
r_4	kiln radius for outer shell thickness, m
R	inner kiln radius, m
Re	Reynolds number = $\rho VD/\mu$
T_a	ambient air temperature, K
T_i	surface temperature
T_{sh}	outer hell temperature, K
T_w	inner wall surface temperature, K
T_1	temperature of surface 1, R
T_2	temperature of surface 2, R
V	volume in the kiln, ft^3
V	gas velocity
x	distance from the burner nozzle, ft

Greek Letters

α_i	fraction of incident radiation which is absorbed by a surface i or gas
α'_g	absorptivity of the gas for its own radiation
γ_L	solid bed half angle
ε_i	surface or gas emissivity
ε'_f	new 'effective' emissivity in the equation for radiant heat from the flame
ε_{sh}	shell emissivity
ε_1	emissivity of surface 1
ε_2	emissivity of surface 2
ρ_i,	surface or gas reflectivity defines the fraction reflected by an opaque solid, which is equal to $1-\alpha_i$.
ρ_a	density of gas entrained in the jet, lb/ft^3
ρ_o	density of jet stream, lb/ft^3
ρ	gas density
τ_g,	transmissivity of the gas is the fraction of radiation transmitted equal to $1-\alpha_g$.
τ_{gi}	gas transmissivities (for black body radiation) for beam lengths corresponding to the original ray, and its first and second reflections
τ'_g	transmissivity of the gas for its own radiation, given by $= 1-\alpha'_g$
τ_{g1}	gas transmissivity for the solid radiation,
σ	Stefan-Boltzmann radiation constant, $W/m^2\ K^4$
μ	viscosity, kg/m s
ω	rev/s

APPENDIX I

GLOSSARY

GLOSSARY

Absorptivity - The fraction of total radiation incident on a surface that is absorbed.

Black body - Idealized body that absorbs all radiant energy incident upon it and emits maximum possible radiation at a given temperature.

Black body radiation - Theoretical rate of radiation from a black body at a given temperature.

Banded radiation - The change in energy level due to changes in vibrational frequency or rotation which manifest themselves in a strong peak at the wavelength corresponding to the vibrational transformation, with multiple rotational energy changes slightly above or below the peak. This type of radiation is characteristic of radiating gases.

Diffuse radiation - When the reflected radiation from a surface is reflected uniformly in all angular directions.

Diffusivity - A measure of the rate with which heat diffuses through a material, evaluated as K/C_p, conductivity divided by specific heat.

Emissivity - Measure of the ability of a substance to radiate energy equal to the ratio (expressed as a decimal fraction) of the radiating ability of a given material to that of a black body.

Emittance - The ability of a surface to emit or radiate energy as compared with that of a black body.

Flux method - A heat transfer method of analysis described in Section 2.2.

Gray body - When at a given temperature the ratio of the monochromatic emissive power of a body to the monochromatic emissive power of a black body at the same wavelength is constant over the entire wavelength spectrum.

Kirchhoff's Law - The monochromatic emittance is equal to the monochromatic absorptance for any surface.

Radiosity - The rate at which radiation leaves a surface per unit area The radiosity is the sum of radiation emitted, reflected, and transmitted.

Reciprocity theorem - $A_1F_{12} = A_2F_{21}$ where A_i is the area of a surface and F_{ij} is the view factor for surface i to surface j.

Reflection method - A heat transfer method of analysis described in Section 2.4.

Reflectivity - The fraction of total radiation incident on a surface which is reflected, $\rho = (1-\alpha-\tau)$.

Resistive Network Method - A heat transfer method of analysis described in Section 2.3.

Specular radiation - When the angle of reflected radiation is equal to the angle of incident radiation.

Theoretical air - (Stoichiometric air) The chemically correct amount of air required for complete reaction or combustion of a given quantity of material.

Thermal conductivity - Measure of the ability of a material to conduct heat. Typical units are Btu-in./ft^2-hr-F.

Transmissivity - The fraction of incident radiation which is transmitted through a body $\tau = (1-\alpha-\rho)$.

View Factor - (Shape Factor) The total diffuse radiation leaving one surface which is intercepted by another surface

Zone Method - A heat transfer method of analysis described in Section 2.1.

VITA

Steven Joel Kirslis was born in Oak Ridge, Tennessee on January 26, 1957. He attended elementary schools in that city and graduated from Oak Ridge High School in January, 1975. He completed his Bachelor of Science degree in Chemical Engineering in 1981. He worked at American Can Company in Shelbyville for two years before returning to the University of Tennessee to begin the Master's degree program in the Fall of 1983. He has worked at IT Corporation in the Thermal Incineration Group since 1984. The work at IT Corporation has been the process design of incineration systems for disposing of hazardous wastes. He received his Master's Degree in Chemical Engineering in June of 1989.